



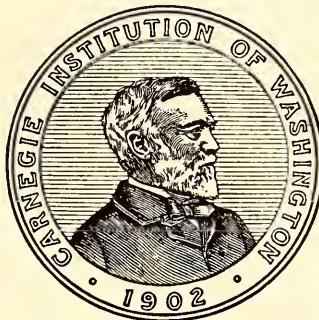
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CARNEGIE INSTITUTION
OF WASHINGTON

YEAR BOOK No. 39

July 1, 1939—June 30, 1940

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CARNEGIE INSTITUTION OF WASHINGTON

WASHINGTON, D. C.

1940

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Organized in 1906, opened in 1907; Arthur L. Day, Director 1907-1936

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Desert Laboratory, opened in 1903, became headquarters of Department of Botanical Research in 1905. Name changed to Laboratory for Plant Physiology in 1923; reorganized in 1928 as Division of Plant Biology, including Ecology.

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ROBERT C. LEE

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Department of Historical Research organized in 1903; Andrew C. McLaughlin, Director 1903-1905, J. Franklin Jameson, Director 1905-1928. In 1930 this Department was incorporated as the Section of United States History in a new Division of Historical Research.

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* Retired January 1, 1941

ORGANIZATION, PLAN, AND SCOPE

The Carnegie Institution of Washington was founded by Andrew Carnegie, January 28, 1902, when he gave to a board of trustees an endowment of registered bonds of the par value of ten million dollars. To this fund an addition of two million dollars was made by Mr. Carnegie on December 10, 1907, and a further addition of ten million dollars was made by him on January 19, 1911. Furthermore, the income of a reserve fund of about three million dollars, accumulated in accordance with the founder's specifications in 1911, is now available for general use and a sum of five million dollars has been paid by the Carnegie Corporation of New York as an increase to the Endowment Fund of the Institution, payments having been completed in 1931. The Institution was originally organized under the laws of the District of Columbia and incorporated as the *Carnegie Institution*, articles of incorporation having been executed on January 4, 1902. The Institution was reincorporated, however, by an act of the Congress of the United States, approved April 28, 1904, under the title of the *Carnegie Institution of Washington*. (See existing Articles of Incorporation on following pages.)

Organization under the new Articles of Incorporation was effected May 18, 1904, and the Institution was placed under the control of a board of twenty-four trustees, all of whom had been members of the original corporation. The trustees meet annually in December to consider the affairs of the Institution in general, the progress of work already undertaken, and the initiation of new projects, and to make the necessary appropriations for the ensuing year. During the intervals between the meetings of the trustees the affairs of the Institution are conducted by an Executive Committee chosen by and from the Board of Trustees and acting through the President of the Institution as chief executive officer.

The Articles of Incorporation of the Institution declare in general "that the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind."

The Institution is essentially an operating organization. It attempts to advance fundamental research in fields not normally covered by the activities of other agencies, and to concentrate its attention upon specific problems, with the idea of shifting attack from time to time to meet the more pressing needs of research as they develop with increase of knowledge. Some of these problems require the collaboration of several investigators, special equipment, and continuous effort. Many close relations exist among activities of the Institution, and a type of organization representing investigations in astronomy, in terrestrial sciences, in biological sciences, and in historical research has been effected. Conference groups on various subjects have played a part in bringing new vision and new methods to bear upon many problems. Constant efforts are made to facilitate interpretation and application of results of research activities of the Institution, and an Office of Publications provides means for appropriate publication.

ARTICLES OF INCORPORATION

PUBLIC No. 260. An Act to incorporate the Carnegie Institution of Washington

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the persons following being persons who are now trustees of the Carnegie Institution, namely, Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, Samuel P. Langley, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, Ethan A. Hitchcock, Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, their associates and successors, duly chosen, are hereby incorporated and declared to be a body corporate by the name of the Carnegie Institution of Washington and by that name shall be known and have perpetual succession, with the powers, limitations, and restrictions herein contained.

SEC. 2. That the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind; and in particular—

- (a) To conduct, endow, and assist investigation in any department of science, literature, or art, and to this end to cooperate with governments, universities, colleges, technical schools, learned societies, and individuals.
- (b) To appoint committees of experts to direct special lines of research.
- (c) To publish and distribute documents.
- (d) To conduct lectures, hold meetings, and acquire and maintain a library.
- (e) To purchase such property, real or personal, and construct such building or buildings as may be necessary to carry on the work of the corporation.
- (f) In general, to do and perform all things necessary to promote the objects of the institution, with full power, however, to the trustees hereinafter appointed and their successors from time to time to modify the conditions and regulations under which the work shall be carried on, so as to secure the application of the funds in the manner best adapted to the conditions of the time, provided that the objects of the corporation shall at all times be among the foregoing or kindred thereto.

SEC. 3. That the direction and management of the affairs of the corporation and the control and disposal of its property and funds shall be vested in a board of trustees, twenty-two in number, to be composed of the following individuals: Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, Samuel P. Langley, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, Ethan A. Hitchcock, Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, who shall constitute the first board of trustees. The board of trustees shall have power from time to time to increase its membership to not more than twenty-seven members. Vacancies occasioned by death, resignation, or otherwise shall be filled by the remaining trustees in such manner as the by-laws shall prescribe; and the persons so elected shall thereupon become trustees

ARTICLES OF INCORPORATION

and also members of the said corporation. The principal place of business of the said corporation shall be the city of Washington, in the District of Columbia.

SEC. 4. That such board of trustees shall be entitled to take, hold, and administer the securities, funds, and property so transferred by said Andrew Carnegie to the trustees of the Carnegie Institution and such other funds or property as may at any time be given, devised, or bequeathed to them, or to such corporation, for the purposes of the trust; and with full power from time to time to adopt a common seal, to appoint such officers, members of the board of trustees or otherwise, and such employees as may be deemed necessary in carrying on the business of the corporation, at such salaries or with such remuneration as they may deem proper; and with full power to adopt by-laws from time to time and such rules or regulations as may be necessary to secure the safe and convenient transaction of the business of the corporation; and with full power and discretion to deal with and expend the income of the corporation in such manner as in their judgment will best promote the objects herein set forth and in general to have and use all powers and authority necessary to promote such objects and carry out the purposes of the donor. The said trustees shall have further power from time to time to hold as investments the securities hereinafter referred to so transferred by Andrew Carnegie, and any property which has been or may be transferred to them or such corporation by Andrew Carnegie or by any other person, persons, or corporation, and to invest any sums or amounts from time to time in such securities and in such form and manner as are permitted to trustees or to charitable or literary corporations for investment, according to the laws of the States of New York, Pennsylvania, or Massachusetts, or in such securities as are authorized for investment by the said deed of trust so executed by Andrew Carnegie, or by any deed of gift or last will and testament to be hereafter made or executed.

SEC. 5. That the said corporation may take and hold any additional donations, grants, devises, or bequests which may be made in further support of the purposes of the said corporation, and may include in the expenses thereof the personal expenses which the trustees may incur in attending meetings or otherwise in carrying out the business of the trust, but the services of the trustees as such shall be gratuitous.

SEC. 6. That as soon as may be possible after the passage of this Act a meeting of the trustees hereinbefore named shall be called by Daniel C. Gilman, John S. Billings, Charles D. Walcott, S. Weir Mitchell, John Hay, Elihu Root, and Carroll D. Wright, or any four of them, at the city of Washington, in the District of Columbia, by notice served in person or by mail addressed to each trustee at his place of residence; and the said trustees, or a majority thereof, being assembled, shall organize and proceed to adopt by-laws, to elect officers and appoint committees, and generally to organize the said corporation; and said trustees herein named, on behalf of the corporation hereby incorporated, shall thereupon receive, take over, and enter into possession, custody, and management of all property, real or personal, of the corporation heretofore known as the Carnegie Institution, incorporated, as hereinbefore set forth under "An Act to establish a Code of Law for the District of Columbia, January fourth, nineteen hundred and two," and to all its rights, contracts, claims, and property of any kind or nature; and the several officers of such corporation, or any other person having charge of any of the securities, funds, real or personal, books, or property thereof, shall, on demand, deliver the same to the said trustees appointed by this Act or to the persons appointed by them to receive the same; and the trustees of the existing

CARNEGIE INSTITUTION OF WASHINGTON

corporation and the trustees herein named shall and may take such other steps as shall be necessary to carry out the purposes of this Act.

SEC. 7. That the rights of the creditors of the said existing corporation known as the Carnegie Institution shall not in any manner be impaired by the passage of this Act, or the transfer of the property hereinbefore mentioned, nor shall any liability or obligation for the payment of any sums due or to become due, or any claim or demand, in any manner or for any cause existing against the said existing corporation, be released or impaired; but such corporation hereby incorporated is declared to succeed to the obligations and liabilities and to be held liable to pay and discharge all of the debts, liabilities, and contracts of the said corporation so existing to the same effect as if such new corporation had itself incurred the obligation or liability to pay such debt or damages, and no such action or proceeding before any court or tribunal shall be deemed to have abated or been discontinued by reason of the passage of this Act.

SEC. 8. That Congress may from time to time alter, repeal, or modify this Act of incorporation, but no contract or individual right made or acquired shall thereby be divested or impaired.

SEC. 9. That this Act shall take effect immediately.

Approved, April 28, 1904

BY-LAWS OF THE INSTITUTION

Adopted December 13, 1904. Amended December 13, 1910, December 13, 1912,
December 10, 1937, December 15, 1939, and December 13, 1940

ARTICLE I

THE TRUSTEES

1. The Board of Trustees shall consist of twenty-four members, with power to increase its membership to not more than twenty-seven members. The Trustees shall hold office continuously and not for a stated term.
2. In case any Trustee shall fail to attend three successive annual meetings of the Board he shall thereupon cease to be a Trustee.
3. No Trustee shall receive any compensation for his services as such.
4. All vacancies in the Board of Trustees shall be filled by the Trustees by ballot. Sixty days prior to an annual or a special meeting of the Board, the President shall notify the Trustees by mail of the vacancies to be filled and each Trustee may submit nominations for such vacancies. A list of the persons so nominated, with the names of the proposers, shall be mailed to the Trustees thirty days before the meeting, and no other nominations shall be received at the meeting except with the unanimous consent of the Trustees present. Vacancies shall be filled from the persons thus nominated, but no person shall be declared elected unless he receives the votes of two-thirds of the Trustees present.

ARTICLE II

MEETINGS

1. The annual meeting of the Board of Trustees shall be held in the City of Washington, in the District of Columbia, on the first Friday following the second Thursday of December in each year.
2. Special meetings of the Board may be called by the Executive Committee by notice served personally upon, or mailed to the usual address of, each Trustee twenty days prior to the meeting.
3. Special meetings shall, moreover, be called in the same manner by the Chairman upon the written request of seven members of the Board.

ARTICLE III

OFFICERS OF THE BOARD

1. The officers of the Board shall be a Chairman of the Board, a Vice-Chairman, and a Secretary, who shall be elected by the Trustees, from the members of the Board, by ballot to serve for a term of three years. All vacancies shall be filled by the Board for the unexpired term; provided, however, that the Executive Committee shall have power to fill a vacancy in the office of Secretary to serve until the next meeting of the Board of Trustees.
2. The Chairman shall preside at all meetings and shall have the usual powers of a presiding officer.

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3. The Vice-Chairman, in the absence or disability of the Chairman, shall perform his duties.
4. The Secretary shall issue notices of meetings of the Board, record its transactions, and conduct that part of the correspondence relating to the Board and to his duties.

ARTICLE IV
EXECUTIVE ADMINISTRATION

The President

1. There shall be a President who shall be elected by ballot by, and hold office during the pleasure of, the Board, who shall be the chief executive officer of the Institution. The President, subject to the control of the Board and the Executive Committee, shall have general charge of all matters of administration and supervision of all arrangements for research and other work undertaken by the Institution or with its funds. He shall devote his entire time to the affairs of the Institution. He shall prepare and submit to the Board of Trustees and to the Executive Committee plans and suggestions for the work of the Institution, shall conduct its general correspondence and the correspondence with applicants for grants and with the special advisers of the Committee, and shall present his recommendations in each case to the Executive Committee for decision. All proposals and requests for grants shall be referred to the President for consideration and report. He shall have power to remove and appoint subordinate employees and shall be *ex officio* a member of the Executive Committee.

2. He shall be the legal custodian of the seal and of all property of the Institution whose custody is not otherwise provided for. He shall sign and execute on behalf of the corporation all contracts and instruments necessary in authorized administrative and research matters and affix the corporate seal thereto when necessary, and may delegate the performance of such acts and other administrative duties in his absence to the Executive Officer. He may execute all other contracts, deeds, and instruments on behalf of the corporation and affix the seal thereto when expressly authorized by the Board of Trustees or Executive Committee. He may, within the limits of his own authorization, delegate to the Executive Officer authority to act as custodian of and affix the corporate seal. He shall be responsible for the expenditure and disbursement of all funds of the Institution in accordance with the directions of the Board and of the Executive Committee, and shall keep accurate accounts of all receipts and disbursements. He shall submit to the Board of Trustees at least one month before its annual meeting in December a written report of the operations and business of the Institution for the preceding fiscal year with his recommendations for work and appropriations for the succeeding fiscal year, which shall be forthwith transmitted to each member of the Board.

3. He shall attend all meetings of the Board of Trustees.
4. There shall be an officer designated Executive Officer who shall be appointed by and hold office at the pleasure of the President, subject to the approval of the Executive Committee. His duties shall be to assist and act for the President as the latter may duly authorize and direct.
5. The President shall retire from office at the end of the calendar year in which he becomes sixty-five years of age.

BY-LAWS OF THE INSTITUTION

ARTICLE V

COMMITTEES

1. There shall be the following standing Committees, *viz.* an Executive Committee, a Finance Committee, and an Auditing Committee.

2. The Executive Committee shall consist of the Chairman and Secretary of the Board of Trustees and the President of the Institution *ex officio* and, in addition, five trustees to be elected by the Board by ballot for a term of three years, who shall be eligible for re-election. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term: Provided, however, that of the Executive Committee first elected after the adoption of these by-laws two shall serve for one year, two shall serve for two years, and one shall serve for three years; and such Committee shall determine their respective terms by lot.

3. The Executive Committee shall, when the Board is not in session and has not given specific directions, have general control of the administration of the affairs of the corporation and general supervision of all arrangements for administration, research, and other matters undertaken or promoted by the Institution; shall appoint advisory committees for specific duties; shall determine all payments and salaries; and keep a written record of all transactions and expenditures and submit the same to the Board of Trustees at each meeting, and it shall also submit to the Board of Trustees a printed or typewritten report of each of its meetings, and at the annual meeting shall submit to the Board a report for publication. The Executive Committee shall have power to authorize the purchase, sale, exchange, or transfer of real estate.

4. The Executive Committee shall have general charge and control of all appropriations made by the Board.

5. The Finance Committee shall consist of five members to be elected by the Board of Trustees by ballot for a term of three years.

6. The Finance Committee shall have custody of the securities of the corporation and general charge of its investments and invested funds, and shall care for and dispose of the same subject to the directions of the Board of Trustees. It shall have power to authorize the purchase, sale, exchange, or transfer of securities and to delegate this power. It shall consider and recommend to the Board from time to time such measures as in its opinion will promote the financial interests of the Institution, and shall make a report at each meeting of the Board.

7. The Auditing Committee shall consist of three members to be elected by the Board of Trustees by ballot for a term of three years.

8. The Auditing Committee shall, before each annual meeting of the Board of Trustees, examine the accounts of business transacted under the Finance Committee and the Executive Committee. They may avail themselves at will of the services and examination of the Auditor appointed by the Board of Trustees. They shall report to the Board upon the collection of moneys to which the Institution is entitled, upon the investment and reinvestment of principal, upon the conformity of expenditures to appropriations, and upon the system of bookkeeping, the sufficiency of the accounts, and the safety and economy of the business methods and safeguards employed.

9. All vacancies occurring in the Executive Committee and the Finance Committee shall be filled by the Trustees at the next regular meeting. In case of vacancy in the Finance Committee or the Auditing Committee, upon request of the remaining members of such

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committee, the Executive Committee may fill such vacancy by appointment until the next meeting of the Board of Trustees.

10. The terms of all officers and of all members of committees shall continue until their successors are elected or appointed.

ARTICLE VI

FINANCIAL ADMINISTRATION

1. No expenditure shall be authorized or made except in pursuance of a previous appropriation by the Board of Trustees, or as provided in Article V, paragraph 6, hereof.

2. The fiscal year of the Institution shall commence on the first day of November in each year.

3. The Executive Committee, at least one month prior to the annual meeting in each year, shall cause the accounts of the Institution to be audited by a skilled accountant, to be appointed by the Board of Trustees, and shall submit to the annual meeting of the Board a full statement of the finances and work of the Institution and a detailed estimate of the expenditures of the succeeding year.

4. The Board of Trustees, at the annual meeting in each year, shall make general appropriations for the ensuing fiscal year; but nothing contained herein shall prevent the Board of Trustees from making special appropriations at any meeting.

5. The securities of the Institution and evidences of property, and funds invested and to be invested, shall be deposited in such safe depository or in the custody of such trust company and under such safeguards as the Trustees and Finance Committee shall designate; and the income available for expenditure of the Institution shall be deposited in such banks or depositories as may from time to time be designated by the Executive Committee.

6. Any trust company entrusted with the custody of securities by the Finance Committee may, by resolution of the Board of Trustees, be made Fiscal Agent of the Institution, upon an agreed compensation, for the transaction of the business coming within the authority of the Finance Committee.

ARTICLE VII

AMENDMENT OF BY-LAWS

1. These by-laws may be amended at any annual or special meeting of the Board of Trustees by a two-thirds vote of the members present, provided written notice of the proposed amendment shall have been served personally upon, or mailed to the usual address of, each member of the Board twenty days prior to the meeting.

ABSTRACT OF MINUTES OF THE FORTY-SECOND MEETING OF THE BOARD OF TRUSTEES

The meeting was held in Washington in the Board Room of the Administration Building on Friday, December 13, 1940. It was called to order at 10:00 A.M. by the Chairman, Mr. Forbes.

Upon roll call, the following Trustees responded: Thomas Barbour, James F. Bell, Frederic A. Delano, W. Cameron Forbes, Walter S. Gifford, Walter A. Jessup, Roswell Miller, Henry S. Morgan, Stewart Paton, John J. Pershing, Elihu Root, Jr., Henry R. Shepley, Richard P. Strong, Charles P. Taft, James W. Wadsworth, Frederic C. Walcott, and Lewis H. Weed. The President of the Institution, Dr. Vannevar Bush, was also in attendance.

The minutes of the forty-first meeting were approved as printed and submitted to the members of the Board.

Reports of the President, the Executive Committee, the Auditor, the Finance Committee, the Auditing Committee, and of Chairmen of Divisions, Directors of Departments, and Research Associates of the Institution were presented and considered.

The following appropriations for the year 1941 were authorized:

Pension Fund	\$60,000
Administration	116,560
Publications (including Office of Publications and Public Relations) ..	67,580
Departmental Research Operations	1,011,467
Research Projects of Limited Tenure.....	80,000

	\$1,335,607

The Chairman reported the death of William Benson Storey, and presented the resignation of Charles A. Lindbergh, which was accepted with regret. With unanimous consent the Trustees proceeded to the election of new members. As a result of balloting, Lindsay Bradford, President of the City Bank Farmers Trust Company, New York City, and Dr. Seeley G. Mudd, of California Institute of Technology, were elected to fill existing vacancies in the Board.

Upon recommendation of the Executive Committee, Article V, Section 3, of the By-Laws of the Institution was amended to read as follows:

ARTICLE V COMMITTEES

3. The Executive Committee shall, when the Board is not in session and has not given specific directions, have general control of the administration of the affairs of the corporation and general supervision of all arrangements for administration, research, and other matters undertaken or promoted by the Institution; shall appoint advisory committees for specific duties; shall determine all payments and salaries; and keep a written record of all transactions and expenditures and submit the same to the Board of Trustees at each meeting, and it shall also submit to the Board of Trustees a printed or typewritten report of each of its meetings, and at the annual meeting shall submit to the Board a report for publication. The Executive Committee shall have power to authorize the purchase, sale, exchange, or transfer of real estate.

CARNEGIE INSTITUTION OF WASHINGTON

Mr. Gifford reported that the Executive Committee, at its meeting of November 8, 1940, voted the following resolution:

"Resolved, That the President of the Carnegie Institution of Washington be authorized to cooperate in the national defense program, and to tender to the United States Government the services of members of departmental and divisional staffs of the Institution, together with equipment and laboratory facilities; and that the President, in his discretion, be empowered to comply with requests from the U. S. Government for services of the Institution, to accept reimbursement from the Government for such expenses as are met by advance of Institution funds, and to take necessary steps for leaves of absence, with assurance of appropriate compensation and maintenance of status, for staff members who may enlist in the military service of the Government, who may be called for training or selective service by the Government, or who may be engaged in other service in connection with national defense."

In support of this action, it was

Resolved, That the Board of Trustees formally and specifically record its approval of the action of the Executive Committee at its meeting of November 8, 1940, providing for full cooperation of the Institution in the national defense program.

The meeting adjourned at 12:00 noon.

REPORT OF THE EXECUTIVE COMMITTEE

FOR THE YEAR ENDING OCTOBER 31, 1940

To the Trustees of the Carnegie Institution of Washington:

GENTLEMEN: Article V, section 3 of the By-Laws provides that the Executive Committee shall submit, at the annual meeting of the Board of Trustees, a report for publication; and Article VI, section 3, provides that the Executive Committee shall also submit, at the same time, a full statement of the finances and work of the Institution and a detailed estimate of the expenditures for the succeeding year. In accordance with these provisions, the Executive Committee herewith respectfully submits its report for the fiscal year ending October 31, 1940.

During this year the Executive Committee held six meetings, printed reports of which have been mailed to each Trustee and constitute a part of this report.

A full statement of the work of the Institution is contained in the report of the President, which has been considered and approved by the Executive Committee, and is submitted herewith. A detailed estimate of expenditures for the succeeding year is also contained in the report of the President, and has been considered by the Executive Committee, which has approved the recommendations of the President in respect thereto and has provisionally approved the budget estimates based thereon and submitted therewith. Close attention has been given both by the Executive Committee and by the Finance Committee to the question of availability of funds for Institution activities in 1941, and budget recommendations are based upon the judgment of these Committees with respect to financial policy in a period of reduced income.

The Board of Trustees, at its meeting of December 15, 1939, appointed Arthur Young and Company to audit the accounts of the Institution for the fiscal year ending October 31, 1940. The report of the Auditor, including a balance sheet showing assets and liabilities of the Institution on October 31, 1940, is submitted as a part of the report of the Executive Committee.

In addition to the report of the Auditor there is also submitted a financial statement for the fiscal year ending October 31, 1940, showing funds available for expenditure and amounts allotted by the Executive Committee, and a customary statement of receipts and disbursements since the organization of the Institution on January 28, 1902. These statements together with the tables in the Auditor's report comprise a full statement of the finances of the Institution.

A vacancy exists in the membership of the Board of Trustees, and also of its Auditing Committee, by reason of the death of William Benson Storey on October 24, 1940. There are no vacancies in the membership of the Executive Committee or Finance Committee.

W. CAMERON FORBES, *Chairman*

ROBERT WOODS BLISS

VANNEVAR BUSH

FREDERIC A. DELANO

WALTER S. GIFFORD

WALTER A. JESSUP

FREDERIC C. WALCOTT

LEWIS H. WEED

November 8, 1940

FINANCIAL STATEMENT FOR FISCAL YEAR ENDING OCTOBER 31, 1940

	Balances unallotted Oct. 31, 1939	Trustees' appropriation Dec. 15, 1939	Revertents and transfers Nov. 1, 1939 to Oct. 31, 1940	Total available 1940	Executive Committee allotments 1940	Transfers by Executive Committee	Unallotted balances Oct. 31, 1940
Large Grants:							
Embryology	\$84,502	\$500.00	\$85,002.00	\$85,002.00			
Genetics	133,715	500.00	134,215.00	134,215.00			
Nutrition Laboratory	18,000	.....	18,000.00	18,000.00			
Tortugas Laboratory . . . . .	.....	1,000.00	1,000.00	1,000.00			
Geophysical Laboratory	157,054	3,500.00	160,554.00	160,554.00			
Historical Research	139,770	.....	139,770.00	139,770.00			
Mount Wilson Observatory	212,549	500.00	213,049.00	213,049.00			
Plant Biology	84,120	1,200.00	85,320.00	85,320.00			
Terrestrial Magnetism	187,942	900.00	188,842.00	188,842.00			
Minor Grants	\$3,443.77	9,865.47	68,409.24	63,600.00	\$3,000.00	\$1,809.24	
Publications	34,841.06	73,440	14,982.76	123,263.82	60,983.91	62,279.91	
Administration	110,300	12,217.20	122,517.20	122,517.20			
Pension Fund	60,000	.....	60,000.00	60,000.00			
General Contingent Fund	50,000	69,944.75	183,344.06	74,800.00	26,017.20	82,526.86	
Carnegie Corporation Emergency Fund	63,399.31	150,000.00	150,000.00	67,200.00		82,800.00	
	\$101,684.14	\$1,366,492	\$265,110.18	\$1,733,286.32	\$1,474,853.11	\$29,017.20	\$229,416.01

AGGREGATE CASH RECEIPTS AND DISBURSEMENTS FROM ORGANIZATION, JANUARY 28, 1902, TO OCTOBER 31, 1940

RECEIPTS	DISBURSEMENTS
<i>Securities Sold or Redeemed</i>	\$69,764,787.34
<i>Interest from Securities and Bank Balances</i>	46,880,916.39
<i>Sales of Publications</i>	346,291.53
<i>Colburn Estate (Bequest)</i>	52,015.74
<i>Harriman Fund (Sale of Land)</i>	4,043.70
<i>Teeple Estate (Bequest)</i>	5,160.62
<i>Carnegie Corporation of New York (Endowment Increase and for Specific Purposes)</i>	8,024,381.24
<i>From Other Organizations and Individuals for Specified Purposes</i>	398,062.94
<i>Pension Fund (Refunds)</i>	86,274.28
<i>Insurance Fund (Refunds)</i>	12,955.51
<i>Administration Building Addition Account, Rentals and Refunds</i>	18,021.09
<i>Miscellaneous Refunds and Receipts</i>	490,626.79
	<i>October 31, 1940, Cash in Banks</i>
	\$126,083,537.17
	\$78,451,506.16
	6,775,586.28
	1,103,670.29
	134,981.36
	63,819.41
	248,706.34
	8,767.52
	309,915.69
	416,206.07
	68,570.96
	40,825.37
	3,722,238.58
	28,336,410.38
	5,283,551.34
	2,735,529.20
	2,326,355.07
	150,000.00
	9,008.82
	\$124,687,648.84
	1,395,888.33
	\$126,083,537.17

* Includes Equipment \$7,206.41, Repairs and Alterations to Old Building \$18,599.29.

REPORT OF AUDITORS

*To the Board of Trustees
Carnegie Institution of Washington
Washington, D. C.*

We have made an examination of the books and accounts of CARNEGIE INSTITUTION OF WASHINGTON for the year ended October 31, 1940.

Income from investments and other sources has been duly accounted for and all disbursements were evidenced by paid voucher checks and/or properly approved invoices. The cash and securities were verified by certificates received from depositories and custodians. As in past years, the detail accounts of the Departments of Research in the field have been audited by the Bursar of the Institution, and we are of the opinion, as a result of reviewing the internal audit methods in force, that such internal audit is satisfactorily conducted.

The securities are stated at cost or value at date acquired, this being the established custom of the Institution. However, in accordance with a recommendation made in February 1940 by the Institution's Finance Committee, all premiums on all obligations purchased subsequent to January 1, 1940 are being amortized on a straight-line basis to the end of the calendar year last preceding the date on which an obligation is first callable or payable at par. The amortization of the premiums applicable to the ten months ended October 31, 1940 amounted to \$7,777.97 and has been deducted from the cost of such obligations.

Real estate and equipment are stated at original cost and books on hand for sale at their sales prices.

We inspected certified copies of the minutes of the meetings of the Board of Trustees and Executive Committee as authority for the appropriations and allotments made during the year.

In our opinion, on the basis of valuations stated above, the accompanying balance sheet, statement of receipts and disbursements, and detailed schedule of securities properly present the financial position of the Carnegie Institution of Washington at October 31, 1940 and the transactions for the year ended that date.

ARTHUR YOUNG & COMPANY
Accountants and Auditors

*New York, N. Y.
November 27, 1940*

BALANCE SHEET October 31, 1940

ASSETS		LIABILITIES	
<i>Investments</i>		<i>Endowment and Other Funds</i>	
Securities.....	\$33,497,445.99	Capital Funds.....	\$29,921,402.52
Cash:	941,307.93	Colburn Fund.....	111,704.13
Awaiting investment.....	27,531.29	Harriman Fund (\$179,628.05	3,166,699.34
Reserved for current needs.....		Included in Property	
		Fund below).....	
		Teepie Fund.....	303,669.96
			5,160.62
			\$33,508,636.57
<i>Property Account</i>		<i>Special Funds</i>	
Real Estate and Equipment at original cost:		Insurance Fund.....	713,384.29
Office of Administration.....		Pension Fund.....	330,932.71
Departments of Research.....		Special Emergency Reserve	
		Fund.....	
		Current Funds, Invested.....	
			276,520.91
			160,000.00
			\$34,989,474.48
		Less Loss from redemption and sale of securities (Awaiting yearly ap- portionment)	\$34,466,285.21
			523,189.27
		<i>Property Fund</i>	
		Harriman Property (Gift).....	
			\$4,383,567.41
		Income Invested.....	179,628.05
			4,565,195.46
<i>General Fund</i>		<i>General Fund</i>	
Cash:		Current Obligations:	
Income account.....	\$427,049.11	Large Grants.....	\$281,567.79
Petty cash and stamps.....	500.00	Minor Grants.....	49,320.08
		Publications.....	91,302.94
		Administration.....	33,025.10
		General Contingent Fund.....	92,621.81
		Carnegie Corporation, Emergency Fund.....	126,032.48
			\$673,870.20
		Unappropriated Fund.....	131,673.70
			\$805,543.90
		Less Current Funds, In- vested (See above)	160,000.00
			\$645,543.90
Books on hand at sale price.....	215,535.70	Value of Publications and Invoices.....	216,273.50
Outstanding accounts on sales of publications.....	737.80	Publication Paper and Sup- plies in Stock.....	2,400.35
Paper and supplies in stock for future publications.....	2,400.35		864,217.75
			\$39,895,698.42
			\$39,895,698.42

CASH RECEIPTS AND DISBURSEMENTS FOR THE YEAR ENDED OCTOBER 31, 1940

RECEIPTS	DISBURSEMENTS	
Securities Redeemed or Sold.....	\$5,022,382.25	
Interest and Dividends from Securities.....	1,427,318.11	
Sales of Publications.....	4,361.22	
Refunds.....	13,047.85	
From Other Organizations and Individuals for Specific Purposes:		
Carnegie Corporation of New York.....	383,000.00	
National Research Council.....	4,080.00	
California Institute of Technology.....	4,999.92	
International Cancer Research Foundation.....	2,062.52	
Rockefeller Foundation.....	1,400.00	
Contributions.....	11,050.00	
Teeple Estate (Interest).....	60.00	
Pension Fund (Refunds).....	4,139.68	
Insurance Fund (Refunds).....	222.00	
Harriman Fund (Sale of Land).....	4,043.70	
	\$6,882,167.25	
Cash in Banks, November 1, 1939	2,050,719.22	
	\$8,932,886.47	
	Cash in Banks, October 31, 1940:	
	Uninvested principal.....	
	Awaiting investment.....	\$941,307.93
	Reserved for current needs.....	27,531.29
	Income Account.....	\$968,839.22
		427,049.11
		1,395,888.33
		\$8,932,886.47

* Includes specific terminating projects administered through departments.

SCHEDULE OF SECURITIES

Aggregate— par or nominal value	Description	Maturity	Cost, amortized cost, or value at date acquired
UNITED STATES GOVERNMENT BONDS			
\$300,000	U. S. Guar. Federal Farm Mtg. Corp., 3s.....	1949-44	\$321,492.18*
300,000	U. S. Guar. Home Owners Loan Corp., 1½s.....	1947-45	304,134.38*
300,000	U. S. of America Treasury, 2s.....	1947	312,796.88*
240,000	U. S. of America Treasury, 2s.....	1950-48	240,000.00
815,000	U. S. of America Treasury, 2½s.....	1956-54	834,218.75
300,000	U. S. of America Treasury, 2½s.....	1948	320,589.84*
\$2,255,000	Total U. S. Government .....	.....	\$2,333,232.03
STATE AND MUNICIPAL BONDS			
\$50,000	City of Cleveland, Cuyahoga County, Water Works, 5½s.....	1967	\$52,984.60
25,000	City of Detroit, Water Supply, 4s.....	1955	24,812.50
25,000	City of Detroit, Water Supply, 4½s.....	1952	25,250.00
50,000	City of Newark, New Jersey, Street Opening, 5½s.....	1958	51,724.94
230,100	City of New York, Corporate Stock, 3s.....	1980	218,595.00
50,000	City of New York, Corporate Stock, 4½s.....	1957	58,531.25
84,000	State of North Carolina, Highway, serial 4½s (\$30,000 registered)	1953-63	92,819.50
50,000	City and County of San Francisco, Hetch Hetchy, 5¾s.....	1960	53,523.34
\$564,100	Total State and Municipal .....	.....	\$578,241.13
FOREIGN BONDS			
\$55,000	Dominion of Canada, 5s.....	1952	\$60,450.00
100,000	Canadian National Ry. Co., 4½s, guar.....	1957	112,000.00
100,000	Canadian National Ry. Co., 5s, guar.....	1969	98,500.00
91,000	Canadian Pacific Ry. Co., coll. trust 5s	1954	90,835.11
105,500	German External Loan of 1924, 7s, std.....	1949	112,713.00
100,000	Province of Alberta, deb. 4½s.....	1958	93,750.00
100,000	Province of Alberta, deb. 5s.....	1950	101,150.00
150,000	Province of Manitoba, deb. 4½s.....	1958	142,886.77
100,000	Province of Nova Scotia, deb. 4½s	1952	100,312.50
100,000	Province of Ontario, deb. 4s	1964	87,150.10
40,000	Province of Ontario, deb. 6s	1943	43,137.50
250,000	Shawinigan Water and Power Co., 1st mtg. and coll. trust s. f. 4½s	1967	238,510.42
100,000	City of Toronto, cons. loan deb. 5s.....	1949	96,164.59
90,000	City of Toronto, deb. 5s.....	1952	89,333.53
\$1,481,500	Total Foreign .....	.....	\$1,466,893.52
PUBLIC UTILITY BONDS			
\$100,000	Alabama Power Co., 1st and ref. mtg. 4½s.....	1967	\$87,265.00
231,000	Alabama Power Co., 1st and ref. mtg. 5s.....	1968	219,516.25
129,000	American Gas & Electric Co., s. f. deb. 2½s.....	1950	131,902.50*
300,000	Appalachian Electric Power Co., 1st mtg. 4s.....	1963	296,250.00
300,000	Arkansas Power & Light Co., 1st and ref. mtg. 5s.....	1956	292,312.50
75,000	Blackstone Valley Gas & Electric Co., mtg. and coll. trust 4s.....	1965	76,875.00
380,000	Columbia Gas & Electric Corp., deb. 5s.....	1961	379,762.50
23,900	Commonwealth Edison Co., conv. deb. 3½s.....	1958	23,910.75
83,000	Commonwealth Edison Co., 1st mtg. 3½s.....	1968	85,712.87
50,000	Consolidated Edison Co. of N. Y., deb. 3½s.....	1948	50,875.00
40,000	Consolidated Edison Co. of N. Y., deb. 3½s	1958	40,730.00
100,000	Detroit Edison Co., gen. and ref. mtg. 4s	1965	103,500.00
325,000	Georgia Power Co., 1st ref. mtg. 5s	1967	320,112.50
200,000	Gulf States Utilities Co., 1st mtg. and ref. 3½s	1969	213,500.00
25,000	Houston Lighting & Power Co., 1st mtg. 3½s	1966	25,750.00
200,000	Illinois Power & Light Corp., 1st and ref. mtg. 5s	1956	196,750.00
25,000	Lone Star Gas Corp., s. f. deb. 3½s	1953	26,406.25
150,000	Louisiana Power & Light Co., 1st mtg. 5s	1957	154,900.00
100,000	Metropolitan Edison Co., 1st mtg. 4½s	1968	109,470.00
100,000	Minnesota Power & Light Co., 1st and ref. mtg. 4½s	1978	92,156.25
50,000	Monongahela West Penn Public Service Co., 1st mtg. 4½s	1960	52,000.00
100,000	Montana Power Co., 1st and ref. mtg. 3½s	1966	101,000.00
100,000	New Orleans Public Service Co., 1st and ref. mtg. 5s	1955	99,200.00
65,000	New York & Westchester Lighting Co., deb. 5s	1954	67,052.50
47,000	North American Co., deb. 3½s	1949	47,822.50
18,000	North American Co., deb. 3½s	1954	18,180.00
10,000	North American Co., deb. 4s	1959	10,125.00
50,000	Northern States Power Co., 1st and ref. mtg. 3½s	1967	47,500.00
100,000	Ohio Edison Co., 1st mtg. 4s	1967	100,266.25

(Continued on following page)

* Includes deduction for amortization of premiums on bonds purchased subsequent to January 1, 1940. Amortization is on a straight-line basis to end of calendar year last preceding date on which bonds are first callable or payable at par.

SCHEDULE OF SECURITIES—Continued

Aggregate— par or nominal value	Description	Maturity	Cost, amortized cost, or value at date acquired
PUBLIC UTILITY BONDS—Continued			
\$100,000	Ohio Power Co., 1st mtg. 3 1/8s.....	1968	\$101,500.00
100,000	Ohio Public Service Co., 1st mtg. 4s.....	1962	102,625.00
200,000	Oklahoma Gas & Electric Co., 1st mtg. 3 1/8s.....	1966	205,000.00
98,000	Oklahoma Natural Gas Co., 1st. mtg. 3 1/8s.....	1955	105,585.20
100,000	Pacific Gas & Electric Co., 1st and ref. mtg. 3 1/8s.....	1961	102,500.00
100,000	Pacific Gas & Electric Co., 1st and ref. mtg. 4s.....	1964	104,000.00
200,000	Pennsylvania Electric Co., 1st and ref. mtg. 5s.....	1962	203,882.50
141,000	Public Service Co. of Northern Illinois, 1st mtg. 3 1/8s.....	1968	145,230.00
60,000	Puget Sound Power & Light Co., 1st and ref. mtg. 4 1/8s.....	1950	56,550.00
50,000	Puget Sound Power & Light Co., 1st and ref. mtg. 5 1/8s.....	1949	31,900.00
300,000	Texas Electric Service Co., 1st mtg. 5s.....	1960	292,700.00
195,500	Texas Power & Light Co., 1st and ref. mtg. 5s.....	1956	200,528.02
120,000	Toledo Edison Co., 1st mtg. 3 1/8s.....	1968	121,800.00
250,000	Union Electric Co. of Missouri, 1st mtg. coll. trust 3 1/8s.....	1962	249,537.50
220,000	Utah Light & Traction Co., 1st and ref. mtg. 5s.....	1944	215,193.00
263,000	Virginia Electric & Power Co., 1st and ref. mtg. 3 1/8s.....	1968	272,205.00
225,000	Wisconsin Electric Power Co., 1st mtg. 3 1/8s.....	1968	232,875.00
\$6,199,400	Total Public Utility.....	.....	\$6,214,414.84
COMMUNICATION BONDS			
\$51,000	American Telephone & Telegraph Co., deb. 3 1/8s.....	1961	\$51,510.00
314,000	American Telephone & Telegraph Co., deb. 3 1/8s.....	1966	326,706.75
125,000	American Telephone & Telegraph Co., s. f. deb. 5 1/8s.....	1943	130,260.62
25,000	Mountain States Telephone & Telegraph Co., deb. 3 1/8s.....	1968	25,500.00
52,000	New England Telephone & Telegraph Co., 1st mtg. 5s.....	1952	51,748.00
75,000	Southern Bell Telephone & Telegraph Co., deb. 3 1/8s.....	1962	72,375.00
\$642,000	Total Communications.....	.....	\$658,100.37
RAILROAD EQUIPMENT TRUSTS			
\$90,000	Erie R. R. Co., 4 1/8s, guar.....	1942-43	\$86,467.90
120,000	Illinois Central R. R. Co., 4 1/8s.....	1942-44	115,184.84
100,000	Missouri Pacific R. R. Co., 4 1/8s.....	1941-42	95,849.61
\$310,000	Total Railroad Equipment Trusts.....	.....	\$297,502.35
RAILROAD BONDS			
\$200,000	Atchison, Topeka & Santa Fe Ry. Co., 1st and ref. mtg. 4 1/8s.....	1962	\$199,500.00
27,000	Baltimore & Ohio R. R. Co., ref. mtg. 4s, std.....	1951	25,312.50
100,000	Baltimore & Ohio R. R. Co., 1st mtg. 4-5s.....	1948	105,700.00
50,000	Central Pacific Ry. Co., 1st ref. mtg. 4s, guar.....	1949	48,250.00
100,000	Chesapeake & Ohio Ry. Co., gen. mtg. 4 1/8s.....	1992	99,464.29
189,000	Chicago, Indianapolis & Louisville Ry. Co., 1st and gen. mtg. 5s.....	1966	189,461.25
35,000	Chicago, Milwaukee, St. Paul & Pacific R. R. Co., 5s.....	1975	31,853.50
140,000	Chicago, Milwaukee, St. Paul & Pacific R. R. Co., conv. adj. mtg. 5s.....	2000	127,414.50
234,000	Chicago, Milwaukee & St. Paul Ry. Co., gen. mtg. 4 1/8s.....	1989	227,162.50
120,000	Chicago & North Western Ry. Co., gen. mtg. 3 1/8s.....	1987	100,300.00
200,000	Chicago & North Western Ry. Co., gen. mtg. 4 1/8s.....	1987	210,000.00
300,000	Chicago, Rock Island & Pacific Ry. Co., 4 1/8s, secured std.....	1952	280,964.50
75,000	Chicago & Western Indiana R. R. Co., cons. 4s.....	1952	70,357.66
300,000	Erie R. R. Co., gen. lien 4s.....	1996	242,937.50
50,000	Great Northern Ry. Co., 1st and ref. mtg. 4 1/8s, std.....	1961	50,113.59
100,000	Great Northern Ry. Co., gen. mtg. 5s.....	1973	104,385.84
45,000	Gulf, Mobile & Ohio R. R. Co., 1st and ref. mtg. 4s.....	1975	27,450.00
30,000	Gulf, Mobile, & Ohio R. R. Co., gen. mtg. income 5s.....	2015	10,875.00
200,000	Kansas City, Fort Scott & Memphis Ry., ref. mtg. 4s (Ctf. of Deposit)	1936	187,250.00
225,000	Lehigh & Lake Erie R. R. Co., 1st mtg. 4 1/8s.....	1957	229,547.29
150,000	Louisville & Nashville R. R. Co., 1st and ref. mtg. 4 1/8s.....	2003	149,475.00
50,000	Missouri, Kansas & Texas Ry. Co., 1st mtg. 4s.....	1990	41,301.56
213,000	Missouri Pacific R. R. Co., 1st and ref. mtg. 5s.....	1977	212,762.50
50,000	New York, Pennsylvania & Ohio R. R. Co., prior lien 4 1/8s.....	1950	52,500.00
50,000	New York, Westchester & Boston Ry. Co., 1st mtg. 4 1/8s.....	1946	49,187.50
50,000	Oregon Short Line R. R. Co., cons. 1st mtg. 5s.....	1946	48,405.15
75,000	Pennsylvania R. R. Co., gen. mtg. 4 1/8s.....	1965	75,918.75
100,000	Pennsylvania R. R. Co., cons. mtg. 4 1/8s.....	1960	104,662.50
50,000	Pittsburgh, Cincinnati, Chicago & St. Louis R. R. Co., gen. mtg. 5s, guar.	1975	51,898.98
42,000	Pittsburgh, Shawmut & Northern R. R. Co., ref. 1st mtg. 4s (Ctf. of Deposit)	1952	4,200.00
100,000	Southern Ry. Co., 1st cons. mtg. 5s.....	1994	103,580.34

(Continued on following page)

SCHEDULE OF SECURITIES—Continued

Aggregate— par or nominal value	Description	Ma- turity	Cost, amortized cost, or value at date acquired
RAILROAD BONDS—Continued			
\$225,000	St. Louis-San Francisco Ry. Co., prior lien mtg. 4s (Ctf. of Deposit) ..	1950	\$203,431.25
70,000	Terminal R. R. Assn. of St. Louis, s. f. gen. ref. mtg. 4s ..	1953	63,603.92
100,000	Toledo & Ohio Central Ry. Co., ref. and imp. mtg. 3½s, guar.	1960	99,000.00
2,084,000	Union R. R. Co., deb. 6s, guar.	1946	2,084,000.00
100,000	Virginian Ry. Co., 1st lien and ref. mtg. 3½s ..	1966	102,250.00
40,000	Wabash R. R. Co., 1st mtg. 5s ..	1939	37,750.00
200,000	Wabash Ry. Co., ref. and gen. mtg. 5s ..	1976	203,250.00
100,000	West Shore R. R. Co., 1st mtg. 4s, guar.	2361	78,140.00
50,000	Western Maryland Ry. Co., 1st and ref. mtg. 5½s ..	1977	42,677.19
\$6,619,000	Total Railroad.....		\$6,376,294.56
INDUSTRIAL AND MISCELLANEOUS BONDS			
\$50,000	Allis-Chalmers Mfg. Co., conv. s. f. deb. 4s ..	1952	\$51,587.00
50,000	Atlantic Refining Co., deb. 3s ..	1953	51,187.50
150,000	Bethlehem Steel Corp., conv. s. f. deb. 3½s ..	1952	148,750.00
227,000	Loew's Incorporated, s. f. deb. 3½s ..	1946	232,963.15
5,000	Phelps Dodge Corp., conv. deb. 3½s ..	1952	5,000.00
140,000	Railway Express Agency, serial notes 1½s-2½s ..	1942-48	140,000.00
100,000	Remington Rand, Inc., deb. 4½s, w. w.	1956	100,162.50
99,000	Republic Steel Corp., gen. mtg. 4½s ..	1956	103,337.50
96,000	Republic Steel Corp., gen. mtg. 4½s ..	1961	99,587.50
100,000	Scovill Manufacturing Co., deb. 3½s ..	1950	102,000.00
400,000	Shell Union Oil Corp., deb. 2½s ..	1954	384,176.25
75,000	Socome Vacuum Oil Co., deb. 3s ..	1964	78,000.00
53,000	Southern Kraft Corp., 1st leasehold and gen. mtg. 4½s ..	1946	51,790.00
100,000	Standard Oil Co. of N. J., deb. 2¾s ..	1953	99,000.00
1,925,000	Tennessee Coal, Iron & R. R. Co., gen. mtg. 5s (payment guaranteed by U. S. Steel Corp.) ..	1951	1,925,000.00
200,000	West Virginia Pulp & Paper Co., 1st mtg. 3s ..	1954	198,000.00
85,000	Wheeling Steel Corp., 1st mtg. s. f. 4½s ..	1966	86,275.00
98,000	Youngstown Sheet & Tube Co., 1st mtg. s. f. 4s ..	1961	96,530.00
\$3,953,000	Total Industrial and Miscellaneous.....		\$3,953,346.40
MORTGAGES			
\$98,482.13	Lawyers Mtg. Co., Guaranteed 1st Mtg. Ctf., Series 18397T, 4% ..	1944	\$98,482.13
100,000	Lawyers Mtg. Co., Guaranteed 1st Mtg. Ctf., 4¼%, No. 29940T ..	1940	100,000.00
80,000	Lawyers Title & Guaranty Co., 5½% Mtg. Par Ctf. No. D 424421381 ..	1935	80,000.00
95,261.23	Lawyers Title & Guaranty Co., Guaranteed 1st Mtg. Par Ctf., 5% ..		
	No. 400572-16 ..	1942	94,784.92
90,000	N. Y. Title & Mtg. Co., Guaranteed 1st Mtg. Ctf., 5½%, No. N97 ..	1938	90,000.00
97,000	N. Y. Title & Mtg. Co., Guaranteed 1st Mtg. Ctf., 4½%, No. N86 ..	1940	97,000.00
90,000	Participating Ctf. in Consol. Bond and Mtg., SE. corner Madison Ave. and 40th St., Manhattan, 4% ..	1944	90,000.00
\$650,743.36	Total Mortgages.....		\$650,267.05
\$22,674,743.36	BONDS AND MORTGAGES—Funds Invested.....		\$22,528,292.25
Number of shares	PREFERRED STOCKS		
120	American Cyanamid Co., 5% cum. conv. pref., 1st ser.		\$1,230.00
410	American Cyanamid Co., 5% cum. conv. pref., 2d ser.		4,766.25
500	J. I. Case Threshing Machine Co., 7% cum. pref.		62,225.00
150	Central Illinois Light Co., 4½% cum. pref.		17,025.00
300	Cleveland Electric Illuminating Co., \$4.50 cum. pref.		34,050.00
2,000	Consolidated Edison Co., \$5.00 cum. pref.		198,725.00
1,125	E. I. Du Pont de Nemours & Co., \$4.50 cum. pref.		116,125.00
1,000	General Motors Corp., \$5.00 cum. pref.		124,875.00
225	Grant Co. (W.T.), 5% cum. pref.		7,642.76
937.5	Gulf, Mobile & Ohio R. R. Co., \$5.00 pref.		8,085.94
400	International Nickel Co. of Canada, 7% cum. pref.		51,903.00
220	Johns-Manville Corp., 7% cum. pref.		27,897.20
1,000	Northern States Power Co., \$5.00 cum. pref.		103,000.00
500	Ohio Oil Co., 6% cum. pref.		52,661.10
400	Oklahoma Natural Gas Co., \$5.50 cum. conv. prior pref.		44,980.25
320	Sherwin-Williams Co., 5% cum. pref.		35,436.80
5,000	U. S. Steel Corp., 7% cum. pref.		715,173.50
14,607.5	Total Preferred Stocks.....		\$1,605,801.80

SCHEDULE OF SECURITIES—Continued

Number of shares	Description	Cost, amortized cost, or value at date acquired
COMMON STOCKS		
2,600	Air Reduction Co.	\$155,863.00
1,600	American Brake Shoe & Foundry Co.	74,304.45
1,400	American Can Co.	128,250.00
5,200	American Cyanamid Co. "B"	149,339.50
5,500	American Radiator & Standard Sanitary Corp.	100,533.00
600	American Telephone & Telegraph Co.	100,312.50
900	American Tobacco Co.	73,424.50
200	American Tobacco Co. "B"	16,342.00
1,500	Bethlehem Steel Corp.	117,325.00
2,300	Caterpillar Tractor Co.	162,360.00
1,600	Chase National Bank of New York	51,800.00
2,400	Chrysler Corp.	226,638.50
2,000	Commercial Credit Co.	96,345.00
2,500	Commercial Investment Trust Corp.	147,824.00
100	Commercial National Bank and Trust Co. of New York	17,880.00
2,500	Continental Can Co.	110,730.00
1,608	Continental Insurance Co.	57,185.30
4,600	Continental Oil Co.	132,433.00
3,500	Deere & Co.	69,662.50
1,760	Dow Chemical Co.	211,240.00
2,200	E. I. Du Pont de Nemours & Co.	348,983.50
1,500	Eastman Kodak Co.	238,952.75
35	First National Bank of New York	60,925.00
10,300	General Electric Co.	407,398.50
1,700	General Foods Corp.	74,426.50
6,800	General Motors Corp.	360,416.00
2,900	Grant Co. (W. T.)	96,781.24
400	Guaranty Trust Co. of New York	104,414.00
1,875	Gulf, Mobile & Ohio R. R. Co.	2,812.50
4,600	Gulf Oil Corp.	174,443.00
700	Hartford Fire Insurance Co.	52,184.68
4,500	Hudson Bay Mining & Smelting Co., Ltd.	148,495.00
3,500	Humble Oil & Refining Co.	203,590.50
900	Ingersoll-Rand Co.	96,960.00
820	Inland Steel Co.	82,930.00
1,000	Insurance Co. of North America	64,962.75
783.30	International Business Machines Corp.	116,998.00
2,000	International Harvester Co.	164,952.50
3,700	International Nickel Co. of Canada, Ltd.	199,217.00
1,113	Johns-Manville Corp.	106,691.00
3,400	Kenncott Copper Corp.	146,532.50
2,500	Kresge Co. (S. S.)	55,725.00
1,100	Liggett & Myers Tobacco Co. "B"	110,625.00
3,000	Monsanto Chemical Co.	304,928.50
4,100	Montgomery Ward & Co.	220,701.08
3,800	National Lead Co.	87,741.00
2,000	Newberry Co. (J. J.)	94,190.00
2,600	New Jersey Zinc Co.	172,294.50
2,500	Owens-Illinois Glass Co.	167,995.00
1,600	Parke, Davis & Co.	72,272.00
1,900	Penney Co. (J. C.)	180,210.00
4,300	Phelps Dodge Corp.	160,704.00
1,200	Pittsburgh Plate Glass Co.	131,399.75
1,800	Proctor & Gamble Co.	100,795.82
1,100	Pullman, Inc.	52,645.00
2,100	St. Joseph Lead Co.	95,386.50
2,500	Sears, Roebuck & Co.	202,234.40
1,500	Sherwin-Williams Co.	147,079.47
8,000	Socony Vacuum Oil Co.	95,645.00
3,100	Standard Oil Co. of California	109,343.00
1,858	Standard Oil Co. of New Jersey	98,627.38
4,000	Texas Corp.	169,108.26
2,200	Timken Roller Bearing Co.	110,436.00
120	Travelers Insurance Co.	59,433.11
3,600	Union Carbide & Carbon Corp.	308,145.50
1,500	United Fruit Co.	109,972.00
1,200	United States Gypsum Co.	120,301.00
900	United States Steel Corp.	92,360.00
2,600	Westinghouse Electric & Manufacturing Co.	280,194.50
167,772.30	Total Common Stocks.....	\$9,363,351.94
182,379.80	COMMON AND PREFERRED STOCKS—Funds Invested.....	\$10,969,153.74
	AGGREGATE INVESTMENTS (BONDS AND STOCKS).....	\$33,497,445.99

REAL ESTATE AND EQUIPMENT, ORIGINAL COST

Administration (October 31, 1940)

Washington, D. C.

Building, site, and equipment.....	\$842,956.88
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Division of Plant Biology (September 30, 1940)

Stanford University, California (Headquarters)

Buildings and grounds.....	\$77,467.56
Laboratory.....	43,333.69
Library.....	24,992.57
Operating equipment.....	<u>16,738.40</u> 162,532.22

Department of Embryology (September 30, 1940)

Wolfe and Madison Streets, Baltimore, Maryland

Library.....	\$3,802.07
Laboratory.....	16,754.28
Administration.....	<u>7,540.47</u> 28,096.82

Department of Genetics (September 30, 1940)

Cold Spring Harbor, Long Island, New York

Buildings, grounds, field.....	\$288,749.45
Operating equipment.....	32,516.03
Laboratory apparatus.....	32,784.19
Library.....	49,686.92
Archives.....	<u>45,488.90</u> 449,225.49

Geophysical Laboratory (September 30, 1940)

2801 Upton Street, Washington, D. C.

Building, library, operating appliances.....	\$230,174.75
Laboratory apparatus.....	167,971.39
Shop equipment.....	<u>20,589.67</u> 418,735.81

Division of Historical Research (September 30, 1940)

Administration Building, Washington, D. C.

Operating equipment.....	\$30,717.27
Library.....	<u>9,769.44</u> 40,486.71

Nutrition Laboratory (September 30, 1940)

29 Vila Street, Boston, Massachusetts

Building, office, shop, and library.....	\$134,293.69
Laboratory apparatus.....	<u>37,261.69</u> 171,555.38

Mount Wilson Observatory (September 30, 1940)

Pasadena, California

Buildings and grounds.....	\$222,458.33
Shop equipment.....	46,715.80
Instruments.....	680,715.60
Furniture and operating appliances.....	143,805.08
Hooker 100-inch reflector.....	<u>633,896.41</u> 1,727,591.22

Department of Terrestrial Magnetism (September 30, 1940)

5241 Broad Branch Road, Washington, D. C.

Building, site, and office.....	\$235,680.13
Survey equipment.....	96,899.75
Instruments, laboratory, and shop equipment.....	<u>391,435.05</u> 724,014.93
	<u>\$4,565,195.46</u>

REPORT OF THE PRESIDENT
OF THE
CARNEGIE INSTITUTION OF WASHINGTON
FOR THE YEAR ENDING OCTOBER 31, 1940

REPORT OF THE PRESIDENT
OF THE
CARNEGIE INSTITUTION OF WASHINGTON

In accordance with Article IV, section 2, of the By-Laws of the Carnegie Institution of Washington, the President has the honor to submit the following report on the operations of the Institution during the year ending October 31, 1940.

The momentous events of the past year do not alter the position of the Institution, as traced in the last annual report; rather do they render its obligations more immediate and pressing. In the midst of intense national effort to provide adequate defense, it is imperative that the Institution respond promptly and effectively to every call from government, and that our facilities be made directly available whenever needed. On the other hand, with so much scientific effort already drawn into war activities in so many countries, the duty of carrying on and providing the continuity essential for best progress rests mainly on the few remaining scientists who can still continue in freedom to extend basic knowledge in a turbulent world.

Fortunately the emergency has brought a quickened pace and a new intensity in scientific activities throughout this country, even in fields which are remote from the preparedness program. When a nation is in danger, and this danger becomes fully appreciated by its people, slumbering loyalties are aroused, petty disagreements disappear, and simple patriotism regains its rightful place. A democracy may exhibit a confusing dissidence in times of peace, but the very freedom of expression which produces discord as each small group pursues its limited objectives acts powerfully to unite and stimulate when common self-interest becomes focused by a single clear threat. Mass thinking takes time to crystallize, and is accompanied always by disturbing impurities and contaminations, but the strength of the resulting product is very great.

CARNEGIE INSTITUTION OF WASHINGTON

Science feels this influence early. The urge to do something for humanity, by improving its knowledge of its environment, is so allied to the urge to do something definite to protect one's country from aggression that all scientific effort responds to the stimulus. This is one of the reasons why fundamental scientific advance, and in fact basic intellectual accomplishment of many kinds, is often accelerated rather than retarded by national stress. This is illustrated, for example, by the magnificent achievements of the coterie of thinkers who appeared in France during the terrible years following the Revolution. Freedom combined with danger brings out some of the finest attributes of the race. The sad part of it is that the danger needs to be clear and immediate in order to be fully operative; and when danger is pressing it may be succeeded by waste and the destruction of moral as well as physical values.

This powerful stimulant has already begun to flow through the veins of the Institution. A quickened tempo is excellent, but we must not let it tempt us to hasty work or conclusions on insufficient evidence. Those scientists whose best work can be accomplished in fields far removed from defense activities should not permit the pressure of the moment to dim the vista of slowly evolving knowledge toward which they advance. The need for more thorough scientific knowledge on which a better civilization can be securely based is not lessened by the hazards that confront it.

For the scientist whose talents apply directly to the means by which a nation defends itself, the way is glaringly clear. He needs to remember that there are many who labor on the unspectacular for every one who manipulates the vital controls, and that the inevitable confusion which accompanies a change in the whole mode of life of a nation necessarily wastes fine capabilities on minor things. He should realize that anonymity and isolation replace the public appreciation and the open scientific fellowship to which he is accustomed. He may well regret deeply that his efforts, so long devoted to an altruistic ideal embracing the whole of mankind, become limited for a time to a narrower national aim. But he shares in that primal joy

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that comes from intense group effort in defense of his home, sublimated it is true, but just as real as though he stood at the mouth of a cave with a few strong men of the clan armed with stone axes against a hostile world.

FINANCES

The income from endowment continues to decrease. The Finance Committee and the Investment Office are faced with an especially grave responsibility in this Institution, where the presence of large continuing obligations renders essential a substantial continuing income. A balance is being maintained between that policy of investment which would impose undue risks upon the future capital position for the sake of large immediate return, and that abrupt curtailment of income, in order to insure capital, which would jeopardize the health of a going concern. Thus far it has been possible to continue all our major efforts without embarrassment, and in fact with sound growth in many areas.

However, the current situation has been transformed during the year by the action of Carnegie Corporation of New York in making to the Institution an emergency grant of \$750,000, payable at the rate of \$150,000 annually for five years. This generosity is keenly appreciated, especially as it comes at a time when the income of the Corporation is sharply curtailed, so that internal readjustment of Corporation plans was necessary in order to make the grant to the Institution possible.

This grant restores the Institution to the sound condition in which a substantial portion of its available funds may be directed toward temporary efforts by its own staff and by others with which it cooperates. Taken together with Institution funds already devoted to such efforts, it makes approximately 15 per cent of the total income available for these purposes. This provides a flexibility which it is highly important to maintain. The emphasis of science shifts with advancing knowledge, and it is essential that the Institution be enabled to redirect its attack accordingly. The Carnegie Institution

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of Washington is more than merely an additional independent research organization in American science. By reason of its scientific scope and its geographic spread the influence of the Institution permeates the entire fabric of the scientific effort of the country in a stimulating and helpful manner. In order that it may fully meet its obligations in this regard, a reasonable amount of flexibility is imperative, and this has now been attained.

For this reason recent budgets have been prepared with the intention of maintaining the balance between long-range obligations and terminating projects. Hence, although the fine accomplishments of many departments indicate ways in which the continuous efforts could be usefully expanded, these opportunities have been generally postponed in favor of temporary projects and grants to cooperating groups. It is, of course, essential that the Corporation grant be applied only to terminating projects, for the grant itself terminates in five years. The need for maintaining fluidity demands such a course and its further extension to that portion of the Institution's income not required to meet continuing obligations of regular operation.

The year 1939 closed with a substantial excess of income over estimates. The present year promises to terminate with close agreement between these two items, so that most if not all of the unappropriated income from 1939 will remain available. By utilizing this carry-over in 1941, and on the basis of income as now estimated, a budget is presented which is balanced without calling on reserves, and provides a sufficient amount in the General Contingent Fund for the extra expenses and readjustments which are normally expected. If income continues to decrease, we shall soon be faced with the alternative of drawing on reserves, of curtailing regular operations, or of sacrificing the desirable flexibility so recently acquired. It is not possible to see far ahead on such matters, and fortunately a decision does not need to be made at this time. Next year it may be necessary to choose. Since we are certainly going through an emergency period, and since we have in the past accumulated an emer-

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gency reserve fund for just such purposes, it may later be wise to draw temporarily on this fund if necessary, in the hope that the emergency may pass.

PLANT AND FACILITIES

A number of changes in our physical plant have occurred during the year.

The small property at Carmel, California, used by the Division of Plant Biology, has been sold. The active program at that locality terminated some time ago, but a portion of the property has since been used by individuals in post-retirement study. As such study could be conducted elsewhere, and as maintenance and depreciation were a burden, it became evident that the property should be sold.

In pursuance of the program reported last year, the activities of the Marine Biological Laboratory at the Dry Tortugas have been terminated. Much of the equipment has been transferred to other laboratories of the Institution. One fairly large boat remained. This has now been presented to the Woods Hole Oceanographic Institution, where it will continue to be fully useful in scientific research.

In terminating our effort at the Desert Laboratory, at Tucson, Arizona, we have succeeded in avoiding the sacrifice of valuable elements. The work of Dr. Shreve will continue under our auspices. Much of the program which the Institution there initiated many years ago has become incorporated into the large operations of the government in connection with forestry, soil conservation, and the public domain. We have therefore transferred the property at Tucson to the Forest Service for use in its research program, which has objectives closely parallel to those which prompted the early establishment of this laboratory. In this connection they plan to maintain the isolated area which has been preserved by the Institution for many years.

The principal addition to plant, reported upon last year, is the cyclotron under construction at the Department of Terrestrial Magnetism with aid of funds from the Carnegie Corporation of New

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York. This particular department, by reason of its nature and location, is already considerably burdened by its efforts for the national government. The construction program, however, is not seriously delayed as yet, and it is still planned to put the cyclotron into operation early next year.

We continue to cooperate closely with the California Institute of Technology in the construction of the great 200-inch telescope. It would not be unexpected if delay in this program were forced by the present emergency. In any case the figuring of the mirror is a time-consuming affair, and completion cannot well be expected in less than eighteen months.

With approval of the Executive Committee, accommodations have been provided in the Administration Building of the Institution for headquarters and offices of the National Defense Research Committee, of which the President is Chairman. In addition a contract has already been effected with this Committee, and others are in contemplation, whereby facilities of the Institution, including personnel and equipment, are being made available for study of defense research problems.

RETIREMENTS

The science of embryology was enormously furthered when the insight of Dr. Mall led to the establishment of the Department of Embryology at Baltimore. He was succeeded by Dr. George L. Streeter, who, after a service of 26 years, during 21 of which he served as Director, has now retired, beloved and admired by all his scientific colleagues. On the invitation of Johns Hopkins University, and with support from Carnegie Corporation of New York, Dr. Streeter will continue with his personal researches there. He has been succeeded in the directorship by Dr. George W. Corner, who comes to us from the University of Rochester. We can look forward to a further period of high accomplishment under his leadership.

The Assistant Director of Mount Wilson Observatory, Dr. Fred-

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erick H. Seares, also retired from active service during the year. We have, in recent years, called upon Dr. Seares for much administrative effort in the affairs of the Observatory, and he has hence been unable to complete before retirement certain important personal research programs. For this reason he has been extended moderate post-retirement support to enable him to finish this work.

Dr. Warren H. Lewis retired from the Department of Embryology after a distinguished career, marked by notable advances which brought to him, and thus to the Institution, wide recognition. He has accepted an invitation from the Wistar Institute at Philadelphia to join them in the furtherance of their biological program.

REVIEW

The Year Book as a whole presents the review of the efforts of the Institution for the year. All that the report of the President can do is to direct attention and to emphasize. There is a certain ineptitude in this procedure, for it does not follow that those results which are most readily summarized in a few simple words are the ones which primarily warrant the attention of the Trustees. Fortunately the reports of the various Directors meet this situation to a considerable extent, for they are largely devoted to summarizing progress in the various fields. The President might therefore restrict this section of his report to the suggestion that these various summaries be consulted. Yet, if it is understood that selecting out certain matters for comment does not imply any listing in order of inherent importance, it is well to direct attention to a number of subjects of special significance and interest, and to comment on their relation to our program as a whole, and on the general objectives before us.

Terrestrial Sciences

There is no word which groups into a single science the physics and chemistry of the materials of which the earth is constructed. The terrestrial sciences are today much subdivided, and the broad term geology no longer embraces them all. Without an understand-

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ing of the way in which this science has grown, the names of our two departments operating in this field might well be misleading. The Geophysical Laboratory deals with the chemistry as well as the physics of the rocks. The Department of Terrestrial Magnetism is as much interested in electric as in magnetic effects, in the body of the earth as well as the atmosphere and ionosphere. The interests of these two departments necessarily overlap. Some day, if terminology could be thereby clarified, we might consider renaming these two groups. Even if we did so, however, the changing trends of scientific interest might soon render the new names inaccurate, unless we were to pursue the unwise procedure of restricting the activities of a group strictly to the scope of its name. This would certainly be unfortunate in these days when groups as far apart in interest as geneticists and physiologists on the one hand, and students of terrestrial science on the other, utilize the same great instrumentalities such as the new cyclotron.

Both laboratories of the terrestrial sciences have a keen interest in the properties of materials under enormous pressures. They have cooperated during the year on a program which substantially extends the limit of experimentation in this regard. The device which makes this possible is a cascaded pressure equipment. This is much more than merely one pressure stage inside another, with each contributing its normal amount to the total pressure produced. The internal stage contributes much more than it could acting alone, for its very presence in a region of high hydrostatic pressure gives it an abnormal strength. It is an ingenious new concept, and Goranson has carefully developed the theory which explains it. We have already reached pressures of 200,000 atmospheres, that is, three million pounds per square inch, and physical measurements of certain kinds can be conducted with material under this pressure. We hope, of course, to learn more in this way of how materials behave deep down in the earth.

Some of the processes by which the earth was molded still continue before our eyes. In volcanoes we can observe violent phe-

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nomena of this sort in action, as our research associate, Perret, has done for many years all over the world. He is now gathering and correlating his findings for publication. We can also make measurements, and our recent expedition to Guatemala tried out some of the methods used in geophysical prospecting as a means of ascertaining subterranean conditions near an active volcano. Finally, in the laboratory, some of the phenomena can be precisely examined on a small scale. One such experiment this year produced a molten rock which, when quenched, frothed into a light pumice. The way in which this takes place is not yet clearly understood, and a full grasp of the matter may well throw a revealing light upon the processes of volcanism.

The science of meteorology has made great strides in recent years, owing to the adoption of new and powerful analytical methods and the keen interest in the subject in connection with aeronautics. The Institution has no large program in the applied aspects of meteorology, but many of the investigations of the Department of Terrestrial Magnetism impinge upon it. A full knowledge of the atmosphere is fundamental to the subject, and our studies of the electrical conditions of the upper layers are of importance in this connection. The use of radio echoes continues to yield important data; and Ellis Johnson has under way as well a considerable program, involving the use of a flickering searchlight, by which the electrical and chemical conditions of the air at great heights may be examined.

Astronomy

As we ascend from the earth, the atmosphere becomes thinner until at a distance of a few hundred miles there is almost nothing. Within the solar system are occasional grains of sand, and the pebbles which sometimes flare briefly as meteors when they strike the atmosphere. Out in space beyond the solar system are dark clouds of dust which obscure the stars, and pose serious problems for the astronomer. These are receiving careful attention from Seares in order that their effects may be properly allowed for. In the vast

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regions beyond the galaxy, in interstellar space, there is very little. But not quite absolutely nothing, for there is a faint sky light which comes to us from a few far-wandering molecules. The nature of these was predicted by McKellar, of the Dominion Astrophysical Observatory, and Adams at Mount Wilson has now confirmed by measurement that at least two organic gases are there present. The power of the spectroscope was never more strikingly demonstrated than by this identification of an organic gas, located at enormous distances from the earth, and so attenuated that it constitutes the least concentration of matter that man has ever studied. Yet there is much space between the stars, and the total amount of matter present in this form may well be a significant element in cosmology.

The science of astronomy is often considered a thing apart from the everyday affairs of this earth, which draws upon the physical sciences for its instrumentation and yields in return only an aid in the development of the physical sciences themselves, in the form of a remote laboratory where strange and extreme physical phenomena can be watched, even if they cannot be controlled. Yet, within the scope of the work of this Institution there are at least three direct interlinkages between astronomy and our other disciplines, by reason of radiations coming to the earth from outer space. The sun is our most important star, and its light furnishes the energy for all our affairs. It enables photosynthesis to proceed, that plants may grow, and animals may be thereby nourished. To this we shall return presently. There are also electrified particles proceeding from the sun, and these affect the condition of our upper atmosphere, so that sunspots and magnetic storms upon the earth are interrelated. Finally, there are cosmic rays falling upon the earth in a continual shower, so that every individual is penetrated through and through during his lifetime by projectiles that disrupt atoms all along their path, sometimes by direct hits which shatter them into small bits. Fortunately these projectiles, as well as those coming from radioactive material of the earth, are not highly concentrated. They may, however, be significant in the process of evolution.

Biological Sciences

At the Department of Genetics there is being investigated, as at other places, the mechanism by which these rays, as well as others such as X-rays and streams of neutrons, cause mutations and hence the appearance of individuals differing in abrupt manner from their ancestors. The study of the ways in which the chromosomes may be split into pieces, and yet rejoin, often in a new arrangement, so that reproduction may proceed, is one of the most fascinating pursuits of all science. It has just been found that a very considerable delay may occur between the fracture and the rearrangement. There are other ways of modifying the process experimentally for study, for example by the use of alkaloids to cause the doubling of chromosomes, and this, under the skillful manipulation of Blakeslee, has produced much new knowledge. The evolution of the individual, as well as the evolution of species, undoubtedly depends upon the genes in the chromosomes, but it is affected as well by other influences. In the individual there is a subtle effect of the environment modifying the direct hereditary process in such a matter as the transmission of susceptibility to disease, as has been found by MacDowell in his studies of leukemia in mice. There is also involved a complex relationship with the endocrine system, furnishing perhaps a mechanism by which the genetic constitution of an individual affects its development, but also perhaps reacting to complicate the genetic process itself. The endocrine secretions, with their powerful influence upon the individual and their strange interrelations, furnish an involved field of study because of the difficulty in strictly isolating individual effects for study. The pigeon, as handled by Riddle, with advanced experimental technique, has proved to be a very useful laboratory object.

The understanding of the evolution of species has proceeded far since the concepts of Darwin and his immediate successors. The interaction between an altering environment and a race of varied genetic constitution does not necessarily result in the appearance of new species. Mutations undoubtedly play a part, but their exact place

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in the process is not yet entirely clear. Much light is now being thrown upon this whole complex matter. The study of the genetic constitution of natural populations of *Drosophila* by Dobzhansky has yielded some unexpected data. At the Division of Plant Biology Clausen, Hiesey, and Keck have summarized in a volume their long-continued transplant experiments, through which some of the mechanisms of evolution which are now in operation among plants of the Pacific slopes are traced back to definite causes. This study, combining a careful evaluation of the genetic situation with a controlled variation of the environment, promises to be of great significance. Clements is rounding out his own study of the matter and promises a comprehensive summary of his opinions and findings.

In the Division of Plant Biology there is also in progress the highly interesting study of several aspects of photosynthesis. Spoehr is using a new method which, though not yet fully developed, promises much. If a seed be grown in the dark, its progress halts as soon as it has used up all its initial food supply, for in the absence of light it cannot manufacture more. It can be artificially fed, however, and it will then proceed. When certain simple substances are injected it cannot develop far, and others must then be supplied. The materials that must be artificially supplied are clearly those for which photosynthesis is necessary, while those which can be omitted are secondary products. The study is not simple, for the process of chemical manufacture in the plant is intricate, so that much work will be necessary before definite conclusions can be drawn. The key may not unlock all the doors, but, in combination with other powerful methods such as the continuing use of radioactive tracers, it should open a further region in the field of the photosynthetic processes of nature.

Study of the evolution of the individual begins with the science of embryology. The mystery which has always surrounded the way in which an apparently simple egg develops into a complex being, with all the consequent fine balancing of physiological processes, still remains. A single cell, sometimes too small to be seen by the naked eye, with microscopic chromosomes, and genes beyond the power

of any optical device, proceeds to subdivide, and soon the resultant cells take on new individuality in accordance with their ultimate destiny in the final structure. Nerve cells interthread the embryo and establish controls. Chemical messengers, the hormones, are manufactured to regulate the joint functioning of distant parts. Bones are deposited to furnish support, channels are built to conduct the fluids by which chemicals are transported. An eye is built; an ear is formed. Finally there emerges a complete being, finely adjusted to carry on a varied existence, and to reproduce itself in turn. The design for all this process was somehow present in the minute egg. With all our science we are still incapable of true understanding of this profound fact. Yet we can trace, record, experiment, and study; and the knowledge grows piece by piece. It is no wonder that embryology leans heavily on its neighboring sciences, and that embryologists strive to reduce their findings more and more to a secure quantitative basis. One occasionally finds a physicist who feels that he now knows much, but one never finds an embryologist who is not humble in the presence of his great problem.

Historical Research

Evolution has many aspects, a principal one of which still remains to be mentioned in closing this report of the Institution's activities. The historian studies the evolution of races in recorded time, and the archaeologist in the time before man inscribed the accounts of his diverse affairs. Kidder has well presented the importance of such researches in these days when the future of all scientific effort is affected by the faulty relations between nations and the power of the instruments of destruction which man has created. The history of man covers but a brief moment in the entire time of a long evolution, but it is a feverish moment in which events occur with startling rapidity. What we are now experiencing is not the first effort of a civilization to acquire a balance for continuing progress, and we are yet to learn much as we continue to unravel the threads of other civilizations which have developed, culminated, and disappeared.

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WILLIAM BENSON STOREY

William Benson Storey died in Chicago on October 24, 1940, at the age of eighty-three, after an outstanding career in engineering practice and administration. He was elected a member of the Board of Trustees of the Institution on December 12, 1924, and served as a member of the Auditing Committee from 1928 to 1939. He always showed continued and helpful interest in the welfare and progress of the Institution and its activities. Only infrequent illness prevented him from attending and actively participating in the affairs of the Board.

By reason of his high ideals, integrity, and wealth of experience, Mr. Storey contributed much toward maintaining and improving the position occupied by the Institution in the world of American science.

VANNEVAR BUSH, *President*

REPORTS OF DEPARTMENTAL ACTIVITIES AND COOPERATIVE STUDIES

ASTRONOMY

Mount Wilson Observatory

Special Projects

TERRESTRIAL SCIENCES

Geophysical Laboratory

Department of Terrestrial Magnetism

Special Projects

BIOLOGICAL SCIENCES

Division of Plant Biology

Department of Embryology

Department of Genetics

Nutrition Laboratory

Special Projects

HISTORICAL RESEARCH

Division of Historical Research

Special Projects

MOUNT WILSON OBSERVATORY

Pasadena, California

WALTER S. ADAMS, *Director*

FREDERICK H. SEARES, *Assistant Director*

The work of an active year at the Observatory has been aided to an unusual extent by the addition of new instruments and the improvement of existing equipment. The remodeling of the 60-foot tower telescope has provided a modern instrument of greatly improved optical quality and high efficiency for continuous records of the sun's surface and detailed studies of the phenomena of its atmosphere. In cooperation with the National Geographic Society the Observatory has designed and helped to construct a special type of telescope and much spectrographic equipment, primarily for the observation of eclipses, but available also for other types of solar investigation. Two stellar spectrographs of unusual design and high light-efficiency have been completed for the study of very faint light-sources such as supernovae, extra-galactic nebulae, and stars of very low intrinsic luminosity. The rotation of extra-galactic nebulae is one of the chief problems now under investigation with these instruments. The use of more transparent glasses, of cameras of special design, and of thin fluoride films to reduce losses by reflection at the optical surfaces has brought within the range of observation objects quite out of reach some years ago.

The maximum of sunspot activity passed nearly two years ago, but, as frequently happens in solar cycles, the maximum was of the "broad" type, with large numbers of spots appearing at intervals over a period of several years. As a result spots have been numerous during the past year and studies of their spectra, especially in the ultraviolet region, and of their magnetic fields have been important features of the solar work. About 96 per cent of the spots observed have signs of the magnetic field in agreement with Hale's law governing the signs in the two solar hemispheres. Certain weak magnetic fields dis-

covered in the vicinity of spots have been found to have signs opposite to those of the spots themselves, and studies of the vortex structure often surrounding spots provide further evidence that the whirls are probably hydrodynamical in origin. The development of a new interference method for measuring weak magnetic fields should be of great value both for investigations of small spots and for the solution of the difficult problem of the sun's general magnetic field.

The important question of the intensities of the dark lines in the solar spectrum has been investigated with a photoelectric monochromator. This instrument measures the energy directly, thus eliminating many of the difficulties of the photographic process; and through refinements of the apparatus, measurements have been extended even to some of the fainter details of the spectrum. The quantity of energy emitted in the spaces between the lines indicates that the sun differs greatly from a black body in its radiation.

Our knowledge of the materials constituting the visible surface of the moon has been notably increased during recent years, mainly through the work of Wright, of the Geophysical Laboratory. During his visits to Mount Wilson he has skillfully applied several methods of approach to this problem, especially through measures of the polarization of the reflected light. Recent observations of a total lunar eclipse agree in indicating that the drop in temperature as the earth's shadow passes across the moon's disk is such as would be expected from a surface covered with a thin layer of fine dust or ash. During totality the temperature dropped from 370° C absolute to 175° .

Planetary observations have been limited to determinations of position of the fainter satellites of Jupiter, including the two discovered by Nicholson about two years ago, and to

some spectroscopic observations of Mars. The amount of water vapor above the equatorial areas of Mars is found to be definitely less than 5 per cent of that in the earth's atmosphere.

Of the many stellar investigations of the year, several have dealt with the brightness, colors, motions, and luminosities of special groups of stars. Accurate measures of brightness are fundamental to all stellar astronomy, and the completion of a catalogue giving the magnitudes and colors of 2271 stars north of declination +80° forms a most valuable contribution to this field. An extension of the sequence of standards of reference to stars as faint as magnitude 20.5 has been found necessary for investigations of nebulae and faint star clouds.

Direct measurements of distance have added several stars to those known to be among the nearest neighbors of the sun. Two of these give out less than one ten thousandth part of the sun's light. Closely related to these trigonometric measures of distance are those of the motions of stars across the sky, their proper motions, which provide average distances and luminosities for classes of stars too distant to be measured directly. Data of this sort, combined with motions in the line of sight, have furnished a new determination of the period of rotation of our galaxy, and of the absorption of light by obscuring clouds in space as a function of distance from the sun.

A direct and valuable measure of space absorption of light is also provided by accurate measurements of the colors of more than 1300 stars, mainly in the neighborhood of the Milky Way. The greater the amount of cosmic dust, the greater is the reddening of the transmitted starlight, and thus the forms of the great irregular obscuring clouds can to a considerable extent be charted and defined. Similar observational material is also serving to determine the ratio of the total absorption of light by the cosmic clouds to the absorption in different colors.

Studies of stellar spectra have dealt in part with the motions of stars as determined from

displacements of the spectral lines, and in part with their physical characteristics. In the first class are the measures of radial velocity of several hundred stars in the Selected Areas of Kapteyn and other special regions, studies of spectroscopic binaries and other stars showing variable radial velocity, and such an investigation as the determination of the solar parallax from the radial motion of Arcturus. To the second class belong the observations of the spectra of several varieties of variable stars, especially the nova-like stars of the SS Cygni type, discoveries and identifications of molecular bands in the spectra of the cooler stars, studies of stars showing emission lines in their spectra, and an extensive investigation of the remarkable eclipsing star ζ Aurigae. Some of the specific results are the discovery of the first known spectroscopic binary of the early Wolf-Rayet type of spectrum; the identification for the first time of molecular bands of SiN, of the carbon isotope in $C^{13}N^{14}$, and of Ca_2 in stellar spectra; the discovery of several double absorption lines in the spectrum of o Ceti; and a determination of the excitation temperature and other physical conditions at a number of levels in the atmosphere of ζ Aurigae.

The interesting problem of the composition of the gases in interstellar space has been studied from several points of view. Marked differences have been found in the distribution of calcium and sodium gases in different regions of space, and also in the relative abundance of calcium and other gases which are now beginning to be identified. The discovery of a faint interstellar line in the spectrum of the relatively near star α Virginis affords a means for calculating the density of the ionized calcium gas in the general region of space near our sun. This proves to be of the order of 3×10^{-10} ions per cubic centimeter, but it is clear that the density is not uniform throughout the galaxy.

Definite evidence of the presence of compounds in interstellar space has resulted from the Mount Wilson observations combined with the theoretical studies of McKellar of the Dominion Astrophysical Observatory and

others. All the important predicted lines of the hydrocarbon gas *CH* have been observed, and the evidence for cyanogen *CN* is nearly as conclusive. It is highly probable that the two or three remaining unidentified sharp lines which are fairly prominent will also be found to be due to the molecules of familiar gases. At present the recognized elements in interstellar gases are neutral and ionized calcium, neutral sodium, neutral potassium, ionized titanium, all in the atomic form, and molecular *CH* and *CN*.

Two nebulae within our galaxy have been investigated for expanding motion and the distance of one of these, the well-known filamentary nebula in Cygnus, has been found to be less than 1000 light-years. Some interesting photographs of galactic nebulae showing unusual detail have been made with red-sensitive plates and Kodachrome films.

In the wide field of study of the extragalactic nebulae, emphasis has gradually been shifting from general surveys to specific problems. This has been particularly true in nebular spectroscopy, where gains in instrumental light-efficiency have made it possible to use higher dispersion than heretofore on important individual nebulae. One valuable result is the establishment with higher accuracy of an extreme point on the velocity-distance curve, a nebula in Boötes showing a red shift corresponding to a radial velocity of +39,000 km/sec. The rotation of one nebula has been studied in detail with the spectrograph, and from among the 1000 brightest nebulae in the northern sky three others have been selected for observation which should yield an answer to the interesting question of the direction of rotation. A program is also being devised for more accurate determinations of the radial velocities of the components of double nebulae, data which would yield values of nebular masses. Existing results suggest an upper limit of mass of the order of 10^{10} suns.

The classification of 800 nebulae brighter than the 13th magnitude has been completed, and the results are now being analyzed. Isolated nebulae are comparatively rare, comprising 5 per cent of the elliptical nebulae and 15 per cent of the late-type spirals. Two

dwarf nebulae of low luminosity have been discovered, characterized by low surface brightness and small color index. These features may prove to be criteria for the discovery of such systems.

A study by Randers of the structural form of nebulae from a hydrodynamical point of view indicates that the ejection of matter from rotating lenticular nebulae is not adequate to produce the observed evolutionary forms. The importance of ring formations arising from viscosity in a differentially rotating system is emphasized as an agency in the process of development.

A quantitative investigation by Holmberg of the clustering tendency of nebulae leads to interesting results from the point of view of the capture theory. Using as reliable values as possible for nebular masses, space velocities, and capture distances, he concludes that a distribution similar to that observed would occur in a stationary universe with random distribution of nebulae in a period of 2×10^{12} years. In a rapidly expanding universe such a distribution would be unlikely to occur unless the expansion were very irregular in nature.

Three supernovae in extragalactic nebulae discovered during the year at Palomar have been observed spectroscopically and their light-curves determined at Mount Wilson. The spectra of the last two represent a new type, differing radically from the spectrum of any supernova observed previously. For a few days after maximum of light the spectrum is continuous, with high intensity in the blue region; the continuous spectrum then begins to fade and broad bright bands develop with widths corresponding to velocities of 5000 km/sec or more on the assumption of expanding shells. Although complete identification is difficult, the main bands including those due to hydrogen can readily be recognized. In general the spectrum resembles that of ordinary galactic novae, but the temperature is considerably higher, of the order of $40,000^{\circ}$ C.

The work of the physical laboratory has included an extensive investigation with the electric furnace of the spectrum of the rare

earth gadolinium, which has been utilized by Russell and Albertson in a term analysis of its exceedingly complex structure. Special attention has also been given to investigations which will aid in the interpretation of solar and stellar spectra, and studies have been made of titanium oxide and carbon bands, including those of the isotope C^{13} , and of the rare element scandium. Of especial application to the results of the photometry of the lines of stellar spectra have been the measurements of the so-called "f-values," statistical factors entering into the intensities of individual lines; and investigations of accurate photometric methods of deriving the intensities of emission lines.

A special study of the extreme ultraviolet absorption spectra of hydrogen and rare gases has been made by Takamine and Tanaka in the physical laboratory. Eight of the lines of hydrogen, most of the resonance lines of neon, and the resonance line of helium at $\lambda 584$ were

observed in absorption and their structure has been thoroughly investigated.

At the close of this brief account of the activities of the past year, the Observatory wishes to record its deep appreciation of the many services of Dr. Frederick H. Seares, who retired as a member of the staff on June 1. Dr. Seares has been associated with the Observatory for thirty-one years, and has served during much of that period as Assistant Director and Editor of the Observatory Publications. His appointment as Research Associate will enable him to continue his photometric investigations.

The death on March 20 of Ferdinand Ellerman removed one of the members of the small group associated with the Observatory from its foundation in 1904. Although he retired from active service in 1937, he retained a profound interest in the Observatory, and his loss is felt most deeply by his associates of many years.

STAFF AND ORGANIZATION

RESEARCH DIVISION

Solar Physics: Seth B. Nicholson, Harold D. Babcock, Joseph Hickox, Edison Hoge, Edison Pettit, Robert S. Richardson, Mary F. Coffeen, Elizabeth S. Mulders, Myrtle L. Richmond, Louise Ware.

Stellar Spectroscopy: Walter S. Adams, William H. Christie, Theodore Dunham, Jr., Milton L. Humason, Alfred H. Joy, Paul W. Merrill, Rudolph Minkowski, Roscoe F. Sanford, Gustaf Strömberg, Olin C. Wilson, Ada M. Brayton, Cora G. Burwell, Dorothy J. Carlson, Alice L. Lowen.

Stellar Photometry: Frederick H. Seares, Walter Baade, Mary C. Joyner.

Nebular Photography and Spectroscopy: Edwin Hubble, Walter Baade, Rudolph Minkowski, Milton L. Humason, Dorothy J. Carlson.

Trigonometric Parallaxes and Proper Motions: Adriaan van Maanen, Ralph E. Wilson, Alice L. Lowen.

Physical Laboratory: Arthur S. King, John A. Anderson, Robert B. King, Edward F. Adams, Ada M. Brayton.

Editorial Division: Frederick H. Seares, Paul W. Merrill, Elizabeth Connor, librarian, Alice S. Beach, secretary and stenographer.

RESEARCH ASSOCIATES

Sir James Jeans, Dorking, England; Henry Norris Russell, Princeton University; Frederick H. Seares, Pasadena; Joel Stebbins, University of Wisconsin.

TEMPORARY ASSOCIATES

Numerous visiting scientists, in addition to the research associates, spent periods of one to several months at the Observatory engaged in special investigations. Among these, Dr. Walter Albertson, of the Massachusetts Institute of Technology, worked on the analysis of atomic spectra; Dr. Dorothy N. Davis investigated bands in stellar spectra; Dr. John C. Duncan, Director of the Whitin Observatory, made photographic observations with the large reflectors; Dr. Leo Goldberg, of the Harvard College Observatory, studied certain

types of stellar spectra; Dr. Erik Holmberg, of the Lund Observatory, was engaged in nebular investigations; Dr. Dean B. McLaughlin, of the University of Michigan, made an extensive study of the available spectrograms of novae; Dr. S. A. Mitchell, Director of the Leander McCormick Observatory, continued his analysis of solar eclipse spectra; Dr. Gunnar Randers, Fellow of Oslo University, carried on theoretical researches on stellar and nebular constitution; Dr. and Mrs. B. W. Sitterly worked on the light-curves of variable stars and on the infrared solar spectrum, respectively; Dr. Lyman Spitzer continued his investigation of M-type stars with the microphotometer; Dr. Toshio Takamine, of the Institute of Physical and Chemical Research at Tokyo, assisted by Dr. Y. Tanaka, investigated the extreme ultraviolet absorption spectra of several gases; Dr. A. E. Whitford, of the University of Wisconsin, collaborated with Dr. Stebbins in photoelectric measurements of early-type stars; and Dr. F. E. Wright, of the Geophysical Laboratory of the Carnegie Institution, assisted by Mr. Hamilton Wright, continued his studies of the materials composing the moon's surface.

OFFICE AND DESIGN

Edgar C. Nichols, instrument design; Harold S. Kinney, draftsman; Anne McConnell, bookkeeper; Gladys Adamson, stenographer and telephone operator.

INSTRUMENT CONSTRUCTION

Optical Shop: John S. Dalton, Donald O. Hendrix, opticians.

Instrument Shop: Albert McIntire, foreman; Elmer Prall, Myo C. Hurlbut, Fred Scherff, Oscar Swanson, machinists; James Chapman, pattern maker; Harry S. Fehr, cabinet maker; Albert Labrow, Donald W. Yeager, assistant machinists.

Operation and Maintenance: Ashel N. Beebe, superintendent of construction; Sidney A. Jones, engineer; Kenneth De Huff, assistant engineer; Thomas A. Nelson, Earl Karr, Glenn C. Moore, night assistants; Anthony Wausnock and Mrs. Wausnock, stewards; Emerson W. Hartong, truck driver; Ellsworth L. Aden, Charles Dustman, Frank Lavers, Arnold T. Ratzlaff, Lester Shade, janitors.

Several individuals whose names are listed above have been associated with the Observatory only a part of the year.

OBSERVING CONDITIONS

Observing conditions during the year July 1, 1939 to June 30, 1940 were slightly below the average for the past 28 years. Stellar observations were made on 282 nights and solar observations on 307 days. The winter was exceptionally warm, with a minimum temperature of 23° F and light snowfall. The total precipitation, however, was 39.62 inches, nearly 7 inches above the average. Of this amount 11.6 inches fell in a single tropical storm during September 24–26, 1939.

The accompanying table shows the distribution by months of the observing nights with the 60-inch telescope.

As in previous years, the 60-inch telescope has been made available to the public for visual observations each Friday night. A popular lecture given by one of the members of the staff precedes the use of the telescope.

MONTH	OBSERVATIONS		
	All night	Part of night	None
1939:			
July.....	26	5	0
August.....	26	4	1
September.....	13	5	12
October.....	23	3	5
November.....	20	6	4
December.....	14	9	8
1940:			
January.....	6	10	15
February.....	7	7	15
March.....	14	6	11
April.....	10	8	12
May.....	23	7	1
June.....	28	2	0
Total.....	210	72	84
Mean 28 years....	204	86	75

SOLAR RESEARCH

SOLAR PHOTOGRAPHY

During the time when the equipment of the 60-foot tower was being remodeled, the daily direct photographs of the sun were taken at the 150-foot tower with the 60-foot focus lens. The regular program of observations with the spectroheliograph at the 60-foot tower was resumed in October 1939.

Solar photographs were made by Hickox, Hoge, Nicholson, and Richardson on 307 days. The approximate number of exposures of each kind was as follows:

Direct photographs	614
H α spectroheliograms of spot-groups, 60-foot focus	210
H α spectroheliograms, 18-foot focus....	810
H α spectroheliograms, 7-foot focus....	13,000
K ₂ spectroheliograms, 18-foot focus....	810
K prominences, 18-foot focus.....	580

SUNSPOT ACTIVITY

During the calendar year 1939, solar observations were made at Mount Wilson on 334 days, on all of which spots were visible. The monthly means of the numbers of groups observed daily for the past two and one-half years are shown in the accompanying table.

MONTH	DAILY NUMBER		
	1938	1939	1940
January.....	8.8	8.4	4.3
February.....	9.7	7.8	5.2
March.....	7.0	8.1	7.7
April.....	8.7	10.8	6.5
May.....	11.3	11.4	5.3
June.....	9.1	10.2	8.3
July.....	13.3	7.5	....
August.....	12.3	8.5	....
September.....	7.9	9.0	....
October.....	9.0	8.1	....
November.....	9.0	6.7	....
December.....	8.4	5.7	....
Yearly average..	9.5	8.5	....

In 1939, 465 sunspot groups were observed, 82 less than in 1938. This decrease occurred mainly in the northern hemisphere, where

220 groups were observed in 1939 and 295 in 1938. In the southern hemisphere 245 groups were observed in 1939 and 252 in 1938.

SUNSPOT POLARITIES

When possible, the magnetic polarities in each spot-group have been observed at least once. The accompanying table indicates the number of spot-groups classified from July 1, 1939 to June 30, 1940. "Regular" groups in the northern hemisphere are those in which the preceding spot has N (north-seeking) polarity and the following spot S polarity. In the southern hemisphere the polarities are reversed.

HEMISPHERE	POLARITY		
	Regular	Irregular	Unclassified
North.....	88	7	62
South.....	135	1	77
Whole sun.....	223	8	139

SOLAR AND SUNSPOT SPECTRA

The 21-foot concave-grating spectrograph of the Solar Laboratory has been utilized by Babcock to trace the characteristics of the sunspot spectrum as far as $\lambda 3044$. Although such observations near the region of atmospheric extinction cannot add greatly to our knowledge of physical conditions in spots, they aid materially in the identification of lines by indicating their excitation potentials. Several spectrograms of spots in the infrared have also been made with this instrument and with the 75-foot spectrograph, and a few bright bridges across spots have been studied in detail. An interesting conclusion is that a bridge is sometimes accompanied by a small high cloud of bright iron vapor seen in moderate motion against the background of the umbra.

Recent infrared spectrograms of the sun's disk taken at the Solar Laboratory are so much superior to previous ones that the region $\lambda\lambda 10500-12200$ is being remeasured.

The inclusion of new and more accurate material will justify the delay of a year in the publication of the joint investigation of the infrared solar spectrum by Miss Moore and Babcock. A comparison of the estimated intensities of band lines of atmospheric oxygen, made by Babcock and Mrs. Coffeen, with the theoretical relative absorption calculated by Allen gives the following simple relations: For intensities fainter than 11 on Rowland's scale, $I = A \log a + B$; for stronger lines, $I = Ca + D$. A , B , C , D are constants, I the estimated intensity, and a the computed absorption. These equations satisfy the data unexpectedly well.

MAGNETIC FIELDS NEAR SUNSPOTS

The magnetic field in sunspots is most intense in the umbra, where the lines of force are nearly perpendicular to the surface. Since lines of magnetic force are continuous, eventually they must turn and re-enter the surface, presumably over a wide area outside the spot. The disturbed appearance of the hydrogen chromosphere near large spot-groups would indicate the presence of extensive fields of force in the vicinity.

To test this question Richardson has measured in regions outside of spots five iron lines, utilizing near-by atmospheric lines as reference standards. Eight plates measured both with a comparator and with a tipping-plate micrometer show the presence of a field with a sign opposite to that of the umbra, and about 5 per cent of its intensity. The field begins at a distance from the penumbra roughly equal to the diameter of the spot, and can be detected outward for five or six diameters.

MEASUREMENT OF WEAK SOLAR MAGNETIC FIELDS

Babcock has applied successfully to measurements of field strengths of a few hundred gauss the polarizing apparatus of his design, attached to the 21-foot spectrograph. For still weaker fields he has obtained excellent results by adding a Lummer plate to the spectrograph. Tests show that magnetic fields of the order of 10 gauss can be studied with this arrange-

ment, and that the equipment is exceptionally well adapted for investigation of the general magnetic field of the sun. A device has been developed for photographing simultaneously on one plate the complete interference pattern from both right- and left-handed analyzers; and a valuable feature is the thick plate of quartz which replaces the familiar quarter-wave plate of mica. By its use displacements of spectral lines resulting from local radial motions in the reversing layer are automatically eliminated. On the resulting photographs the position of each component of each line is determined from 10 interference fringes which are relatively easy to measure; and the effect of any distortion of the gelatine film as a source of error is greatly reduced.

In connection with this investigation Mrs. Coffeen has completed a survey of all identified and analyzed solar lines between $\lambda 4400$ and $\lambda 6100$ to aid in the selection of lines with the most suitable magnetic patterns.

SOLAR VORTICES

An investigation by Richardson of the direction of whirl in hydrogen vortices on spectroheliograms taken from 1908 to 1939 has confirmed the earlier work of Hale based on fewer data. The vortices appear to be hydrodynamical in origin, with their direction of whirl determined principally by the solar rotation. No connection was found between the direction of whirl and the polarity of spots. Open whirls greatly predominate, although closely wound spirals do occur.

CHROMOSPHERIC DISTURBANCES

Since bright chromospheric disturbances are almost invariably associated with spot-groups, it would naturally be assumed that their frequency is a function of the number of spot-groups and of the length of time they are observed. An examination by Richardson of our records for the past five years, however, shows no evidence for such a simple relation. The disturbances seem to occur sporadically, their appearance probably depending more upon peculiarities of the individual spots themselves than upon sunspot activity in general.

ESCAPE OF PROMINENCES FROM THE SUN

Pettit has collected measurements of the heights of 61 prominences observed during eruption since 1885 and has published a catalogue describing their principal features. The time-height plots for these prominences usually show constant velocities increasing suddenly at intervals. The only prominence which surpassed the critical velocity for any elevation above the sun was no. 47, observed at Lake Angelus in 1937.

An examination of the entire material shows that in general the theoretical time-height plot of a body moving freely under solar gravitation deviates widely from that observed for prominences. In no. 47, however, the final velocity, 728 km/sec, cannot be distinguished from that given by the theoretical curve. No theory of prominence motion will account for eruptive prominences, but the uniform motions of these objects suggest their ultimate escape at any velocity, although we do not know that this velocity persists after the atoms lose their excited state. On the other hand, coronal prominences and the birth of streamers over sunspots suggest that eruptive prominences disintegrate and eventually return.

IMPROVEMENTS IN THE SPECTROHELIOSCOPE

Pettit has improved considerably the optical performance of the Hale spectrohelioscope by placing a reversing prism just behind the first slit, thereby making the instrument fulfill the correspondence condition. A mechanical improvement is effected by mounting the prisms individually on small synchronous motors of the shaded-pole type with loose flywheels to damp out any tendency to hunt. With this change almost any solar spectroscope or spectrograph may be converted into a spectrohelioscope.

ENERGY MEASUREMENTS IN THE SOLAR SPECTRUM

From photoelectric tracings obtained with the 21½-foot monochromator, Pettit has determined the intensities of groups of lines in

the regions $\lambda\lambda 3200-3300$ and $\lambda\lambda 3900-4000$. A comparison of the equivalent widths with the results of Mulders shows an average ratio of 0.81. Improvements in the monochromator have made possible the use of slits as narrow as 0.02 mm and have revealed lines as faint as —1 on the Revised Rowland scale.

ULTRAVIOLET ENERGY-CURVE OF THE SUN

Measurements carried out at Tucson in 1931 were repeated by Pettit on Mount Wilson in 1934, 1937, and 1939 with improved equipment. Observations on 35 days in this period when the sky was very transparent yield intensity measurements for 100 angstrom units between $\lambda 0.7\mu$ and $\lambda 0.292\mu$. The average energy-curves for the center of the disk and for integrated light verify those obtained at Tucson, in particular a sudden drop of 48 per cent in intensity from $\lambda 0.40$ to $\lambda 0.38\mu$, a nearly constant intensity from $\lambda 0.38$ to $\lambda 0.325\mu$, and a nearly linear fall to a very low value at $\lambda 0.292\mu$.

The atmospheric transmission coefficients obtained from the measurements throughout the spectrum differ not more than 2 per cent from the Smithsonian values until the ozone band is reached. Measures in this region indicate an atmospheric ozone content of 0.1 cm at normal temperature and pressure. The ratio of the energy in spaces between the absorption lines to the average in the spectrum was determined with the photoelectric cell attached to the 21½-foot concave-grating monochromator. When these coefficients are applied to the thermoelectric measures the resulting curve for energy between the lines is still quite different from that of a black body.

A laboratory study of the ozone spectrum shows that the lines in the Huggins band are so feeble that they will not be distinguishable in the solar spectrum and cannot account for the depressions found in the photoelectric energy-curves.

ECLIPSE SPECTROGRAPH

Early in 1939, the National Geographic Society proposed as a cooperative undertaking

the construction of a spectrograph to be used at future solar eclipses for the photography on a large scale of the flash spectrum and the spectrum of the extreme limb of the sun. The instrument has been completed on this basis, the National Geographic Society providing the cost of all materials and the expense of nearly all the machine work, while Dunham of the Observatory staff has furnished the design and has supervised the construction. Some special optical and machine work has been done in the Observatory shops.

The telescope is of the tower type with mirrors of fused quartz. The spectrograph, with two aluminium-on-glass plane gratings by Wood, has many novel features. One grating forms a spectrum through the ultraviolet and blue; the other through the green, yellow, and red. The spectra are focused by three 30-inch spherical mirrors of 15 feet focal length, placed horizontally in the bottom of the pit under the tower and adjusted in position to perform as nearly as possible like a single 90-inch mirror. The two parts of the spectrum, each 45 inches long, are focused on photographic plates carried on two light fabricated aluminium drums, 30 inches in diameter, carefully machined to the circular form required to bring every part of the photo-

graphic emulsion into focus. These plate-holder drums are turned by a special Geneva motion which will permit 36 alternate long and short exposures on the solar crescent. The dispersion is approximately 1.8 angstroms per millimeter.

The instrument may be used either with or without a slit. Two images of the sun are formed by two pairs of cylindrical mirrors, having focal lengths of 46 inches and 22 feet, respectively. These produce two elliptical images, in which the ratio of major to minor axes is approximately 6:1. The orientation will be chosen so that the major axis lies parallel to the length of the crescent. This arrangement should combine the advantages of Anderson's minified image for reducing atmospheric effects with the advantages of a larger scale in the other coordinate. Spectra more than an inch wide will permit accurate measurements of positions on the solar image.

The war has necessitated abandonment of the plan of the National Geographic Society for sending this equipment to South Africa for use at the eclipse of October 1, 1940. It will, however, be available for later eclipses and meanwhile is excellently adapted for several fields of spectroscopic research on the sun.

LUNAR AND PLANETARY INVESTIGATIONS

SURFACE FEATURES OF THE MOON

Dr. Fred E. Wright, of the Committee on Study of the Surface Features of the Moon, has continued work on the method for measuring the amount of polarization in moonlight by use of a photoelectric cell, an alternating-current amplifier, and a rotating polarizing prism. Comparison of this method with that in which a photoelectric cell, a direct-current amplifier, and a polarizing prism or a quartz Wollaston prism are used is now in progress. Some advance has also been made in the measurement of the slope angles of lunar surface features through use of the series of moon photographs taken in 1938 with the 100-inch telescope. This task is time-consuming; but topographic maps of many of the craters and mountains on the moon are

gradually being produced which will be useful later in connection with detailed physiographic studies of the moon's surface.

The report on the results of visual measurements of the percentage polarization in light from different parts of the moon's surface and in sunlight scattered by terrestrial materials at different phase angles is in preparation. Plans had been made to complete this report during the past winter; but unexpected tasks intervened and seriously interfered with the work.

RADIATION MEASUREMENTS ON THE ECLIPSED MOON

Measurements made by Pettit with a thermocouple on the 20-inch telescope at the eclipse of October 27, 1939 on a point near

the center of the disk showed that the temperature fell from 370° K to 200° K during the first partial phase and dropped slowly to 175° K during totality. At the beginning of totality the rate of fall was 30° C per hour, but at the end of the first hour of total eclipse it was 7° C. A total of 39 sets of determinations both with water cell and with microscope cover glass were obtained.

The rate of radiation is nearly proportional to the energy received except for very low temperatures. A computation based on the physical constants of lava and the radiation data shows that a surface layer 2.6 cm thick is all that seems to take part in the exchange of heat.

WATER VAPOR IN THE SPECTRUM OF MARS

Seven spectrograms of Mars in the region near $\lambda 7000$, taken by Adams and Dunham with the coudé spectrograph, have been studied by Adams for the presence of possible Martian components of the terrestrial water-vapor lines. Four of the spectrograms were

taken when Mars was approaching the earth, and three when it was receding. Hence the effect of a Martian component should be to displace the measured wave lengths of the terrestrial lines between these two epochs. No appreciable displacement was found, and the conclusion is that at the center of the disk the amount of water vapor in the atmosphere cannot exceed 5 per cent of that in the atmosphere of the earth.

SATELLITES OF JUPITER

All the known distant satellites of Jupiter have been observed by Nicholson and accurate positions derived from the photographs.

The orbit of J IX has been recomputed from the observations of 1939. With this orbit the positions of J IX were calculated back to the opposition of 1938 and ahead to that of 1940, taking into account the attractions of Jupiter and the sun. Miss Richmond has assisted in the measurement and reduction of the plates and in the computation of the orbit.

MISCELLANEOUS STELLAR INVESTIGATIONS

TRIGONOMETRIC PARALLAXES AND PROPER MOTIONS

Of the 21 stars measured by van Maanen for parallax, 2 have been found to lie within 5 parsecs of the sun. These are Ross 128 and Luyten 789-6, with parallaxes of $0.^{\circ}289 \pm 0.^{\circ}007$ and $0.^{\circ}317 \pm 0.^{\circ}007$, respectively. The total number of stars now known to lie within 5 parsecs is 37. In addition 13 companions to these near-by stars are known. Among the 21 stars measured, 17 have absolute photographic magnitudes fainter than +10, and three fainter than +15.

Second-epoch plates of 30 Cepheid variables have been obtained by van Maanen during the year. Thirteen of these, for which the interval between observations has been 10 years or more, have been measured. The probable errors of the final proper motions determined from three pairs of exposures are $0.^{\circ}001$ in each coordinate. The proper

motions of 4 Cepheids have been measured by both van Maanen and R. E. Wilson.

RELATIVE PROPER MOTIONS OF VARIABLES

Measures have been made by R. E. Wilson of 20 fields containing variables, mainly of the δ Cephei and RR Lyrae classes, on plates covering intervals of 10 to 14 years. These were taken by van Maanen for the determination of relative proper motions. The probable errors of the determinations are about $\pm 0.^{\circ}0013$ per annum in each coordinate.

FAINT PHOTOMETRIC STANDARDS

Using the platinum half-filter method, Baade, with the assistance of H. F. Weaver, has extended the photographic scale to mag. 20.5 in the two Selected Areas 57 and 61. The accuracy attained together with the economy of the method have led to a plan to

extend the photographic scale to the same limit—with careful checks of the zero points used—in every third area of the $+15^{\circ}$ zone, starting with S.A. 68. In view of the urgent need of reliable sequences fainter than mag. 17, it is to be hoped that arrangements can be made to insure completion of the program within the next two years.

PHOTOMETRIC CATALOGUE OF POLAR STARS

Seares and Miss Joyner have continued the preparation of the catalogue of magnitudes and colors of stars north of $+80^{\circ}$ declination undertaken jointly with Dr. Ross of the Yerkes Observatory. The manuscript of the catalogue, which includes 2271 stars, is now ready for the printer, and the extensive discussions of the internal consistency of the magnitudes are nearly finished. A gratifying result is the uniformity of the zero point for different intervals of right ascension and declination. The fluctuations do not exceed 0.02 mag. and for most of the groups of stars tested are 0.01 mag. or less. Except for final revisions, the detailed account of the investigation given in the introduction to the catalogue is also finished.

SPACE ABSORPTION

In a survey of the problems of space absorption Seares has suggested that the total absorption in any direction within the zone of avoidance may be regarded as consisting of two parts, one contributed by the dust clouds that outline the zone, the other arising from the more homogeneous medium that causes the decrease in the counts of extragalactic nebulae as the zone of avoidance is approached. The clouds are so scattered that their contribution is erratic and should show little correlation with distance. The absorbing medium, on the other hand, is a stratum of such uniformity that the cosecant law holds with good approximation down to the edge of the zone of avoidance, in latitudes as low as 10° at least. The point of the suggestion is that the "stratum" is effective in producing absorption in still lower latitudes,

although the simple cosecant law may no longer hold. The colors of B-type stars observed by Stebbins, Whitford, and Kron, and especially the behavior of the minimum color excess with increasing distance, seem to harmonize with this viewpoint.

COLORS OF B AND A STARS

The catalogue of photoelectric colors of 1332 B-type stars observed by Stebbins and Whitford has been published. The reddened B stars give a convenient measure of the selective absorption in different regions, but the colors are also good indicators of unidentified supergiant B stars seen at great distances. The clouds of cosmic dust near the plane of the galaxy are so irregular that an average coefficient of absorption should be taken with caution. For this reason the values of the photographic absorption, 0.67 mag./kpc by Trumpler from open clusters, 0.85 mag./kpc by Joy from Cepheid variable stars, and 1.1 mag./kpc from the B stars, are not necessarily inconsistent. Forty per cent of the clusters are in latitudes higher than 5° , the limit for the B stars, and the Cepheid variables may also be in regions clearer than the average.

Stebbins and Whitford have continued spectrophotometric measures of B stars to determine the law of space reddening (known to vary approximately as $1/\lambda$) and thus to determine the ratio of total to selective absorption by the interstellar material.

Photoelectric measures of A stars near the north pole of the galaxy indicate an absorption of not more than 0.10 mag. in the first hundred parsecs, compared with 0.25 mag. for the total galactic absorption in that direction from counts of nebulae.

GALACTIC ROTATION AND ABSORPTION

The radial velocities of O and B stars, Cepheid variables, non-Cepheid c stars, and interstellar gases, extending out to a true distance of about 2000 parsecs, have been analyzed by R. E. Wilson to determine the value of the galactic rotation constant, A . The

values derived from objects at different distances are brought into fair agreement by assuming a mean effective absorption of 0.65 mag./kpc for both visual and photographic light. Since the distribution of the absorbing matter is not uniform, this assumption does not lead to a true value of A . A linear relation between the observed values of A and the photometric distances brings all the values into satisfactory accord and gives a mean value,

$$A = 17.7 \pm 0.7 \text{ km/sec/kiloparsec.}$$

Applied to visual and photographic distance sequences, this value of A gives values of the mean absorption consistent with those derived on the assumption of uniform distribution.

LUMINOSITY SEQUENCE FOR C STARS

A study by R. E. Wilson of the mean visual absolute magnitudes of the non-Cepheid c stars shows a marked decrease in luminosity with advance in spectral type. The values of \bar{M} show the following progression: B₀, -5.4; A₀, -4.9; F₀, -4.4; G₀, -3.8; K₀, -2.6; K₅, -2.0.

SPECTROSCOPIC AND TRIGONOMETRIC ABSOLUTE MAGNITUDES

Two investigations of the accidental and systematic errors in spectroscopic absolute magnitudes of stars of the main sequence have been completed, the first by Russell and Miss Moore, and the second by Strömgberg. In the first of these the mean values obtained by grouping the spectroscopic and trigonometric material according to reduced proper motion (which is equivalent to grouping by H) have been discussed in detail. The results substantially confirm those of an earlier investigation by the same authors but make the dispersions slightly smaller. The numerical agreement with the values obtained by Strömgberg by a different method is good. Of the two regression lines, the first of which corresponds to means selected according to the spectroscopic absolute magnitude, Russell

and Miss Moore prefer the second for general catalogue purposes.

Strömgberg's investigation was prompted by the work of Russell and Miss Moore, who pointed out the importance of the grouping of the stars as affecting the calibration curves to be used. If M_s represents the spectroscopic and M the true absolute magnitude, Strömgberg concludes that the first regression line (M on M_s) should be used for calibration when the stars are grouped on a basis depending directly upon M_s or the special spectral criteria which determine M_s ; while the second regression line (M_s on M) should be used for groupings according to M , or in practice according to the apparent magnitude m or the reduced proper motion. Spectroscopic absolute magnitudes calibrated by the first and the second regression lines, respectively, may be denoted by M'_s and M''_s .

The accompanying table gives the mean errors of M_s , the symbol ϑ referring to the values published in Mount Wilson Contribution, No. 511, and ϑ' and ϑ'' to the mean errors of M'_s and M''_s . The values ϑ'' are always larger than ϑ' .

	F	G0-G7	G8-K2	K3-K9	M0-M9
$\vartheta \dots$	0.60	0.51	0.75	0.42	0.58
$\vartheta' \dots$	0.27	0.41	0.49	0.32	0.56
$\vartheta'' \dots$	0.45	0.60	0.65	0.39	0.62

DIRECT PHOTOGRAPHY

Dr. Duncan used the 60-inch and 100-inch telescopes on a few nights during the summer of 1939 for direct photographic observations of a number of selected objects. These included NGC 6357, the dark nebula Barnard 143, and one or two stellar fields, on red-sensitive plates; NGC 4621, 4636, and 6946, observed for supernovae; R Aquarii, and several stellar fields in low latitudes; and M 11, M 15, M 31, χ Persei, the Orion nebula, and NGC 7662, photographed on Kodachrome films.

STELLAR SPECTROSCOPY

Investigations in stellar spectroscopy have covered a very wide variety of objects, ranging from faint supernovae to the brightest stars. A new spectrograph of unusual design which has been under construction in the instrument shop and is nearing completion should greatly facilitate observations of faint stars and nebulae with somewhat higher dispersion than that hitherto employed. Two light flint prisms and a collimating mirror are used with cameras of the Schmidt or lens type ranging in focal length from 3 to 18 inches. The transmitting surfaces in the entire optical system have been treated with an evaporated coat of fluorite with a marked gain in light efficiency. The same process is now being applied to the surfaces of the prisms and lenses in the other stellar spectrographs.

Another small spectrograph of the "broken" type for use at the Newtonian focus of the large reflectors has been completed and used during a part of the year. The collimator is a parabolic mirror and the beam of light between the collimator and prisms is deviated by an inclined plane mirror near the focus of the telescope. The plane mirror has a hole near the center, sufficiently large to transmit the beam from a long slit. Comparisons with the small Cassegrain spectrograph indicate that for equal dispersions the field and the photographic efficiency of the two instruments are essentially the same, but that much fainter objects can be seen and centered at the Newtonian focus. An important practical advantage is that by removal of the slit the Newtonian spectrograph can be used as a slitless instrument to record small-scale spectra during a program of direct photography without the necessity of changing cages on the telescopes.

The 114-inch Schmidt camera used in the coudé grating spectrograph at the 100-inch telescope has proved to be remarkably efficient in observations of bright stars with high dispersion. The absence of glass in the optical system leads to excellent transmission in ultraviolet light, and exposure times have proved

to be considerably shorter than expected. Stars of the 4th magnitude are now readily observable with a linear dispersion of 2.9 angstroms to the millimeter.

The so-called "blind" spot in the center of the extrafocal beam of the reflectors due to auxiliary mirrors makes it impossible to use spectra taken with the image slicer and cylindrical lens for photometric purposes. This is because the cylindrical lens is used to focus the grating upon the photographic plate. To overcome this difficulty Dunham has designed a system of quartz prisms of small angle for use at the coudé focus of the 100-inch telescope. Two prisms placed 56 inches above the focus direct a portion of the eastern and western areas of the circular beam into the blind spot, where two other small prisms receive the light and send it to the slit and collimator. The focus of this light is the same as that of the main beam, the system is achromatic, and through prisms of suitable size the blind spot should be completely eliminated. The equipment is now under construction and will soon be tested.

Dunham has also designed an instrument for providing satisfactory calibration spectra, especially in the ultraviolet region, at the coudé focus of the 100-inch telescope. The device resembles in principle the van Cittert monochromator, in that it employs two spectrographs in tandem. A single aluminized spherical mirror and a 30° quartz prism with aluminized rear surface are used, and the spectral distribution is finally regulated by a diaphragm or an unevenly aluminized transmission plate placed at the focus.

Approximately 1400 stellar spectrograms have been obtained with the various instruments during the year.

RADIAL VELOCITIES

Measurements of the radial velocities of variable stars of types Me and Se have been continued by Merrill and Miss Burwell, and this program is nearing completion. About 150 additional stars have been observed since

the last statistical discussion, and many of the previous objects have been reobserved. Special attention is being given to the relative displacement of emission and absorption lines, and to lines in the ultraviolet region.

Radial-velocity observations and measurements of stars in the Selected Areas have been continued regularly by Strömb erg, Christie, and Miss Lowen, and one or more spectrograms have now been obtained for 257 of the 297 stars on the program. A star in this list, BD +30°2611, has the remarkable radial velocity of -278 km/sec. A number of B- and A-type stars in special regions of the sky are under observation at the request of Dr. Bok, of the Harvard College Observatory, the measured radial velocities serving as an aid in the determination by his method of velocities from spectra taken with the objective prism.

The first known spectroscopic binary having a spectrum of the Wolf-Rayet type was discovered by O. C. Wilson and has been under investigation by him. Two spectra are present, one of type WN₅ and the other of early B. The minimum mass of the Wolf-Rayet star is 9.74 times the sun's mass, and that of the B star, 24.8. The orbits of the two stars show a difference of 90 km/sec in the positions of the γ axes, which is believed to represent a shift in wave length of the Wolf-Rayet bands. If, as some evidence from the work of Beals indicates, such a shift may be a common if not universal phenomenon in Wolf-Rayet spectra, it will be a matter of fundamental interest to determine its source.

Another remarkable star is 48 Librae (HD 142983). Merrill and Sanford found that between 1935 and 1939 the radial velocity derived from the metallic lines and the ultraviolet hydrogen lines decreased about 100 km/sec and then returned to its previous value. Meanwhile the hydrogen lines H β , H γ , and H δ were displaced only about one-half as much. At present both groups of lines are showing a tendency to give algebraically higher values of the velocity.

The bright star Rigel and its companion have been studied by Sanford with the coudé spectrograph. The known variation in the

radial velocity of Rigel has been confirmed but no definite period has as yet been derived. The H and K lines each show a sharp component, apparently of stellar origin, and the structure of the main H and K lines seems to be complex. The spectrum of the companion to Rigel has numerous lines which are definitely double at times. It is presumably a spectroscopic binary with a period, not as yet precisely determined, of a few days.

Measurements of the displacements of the H and K lines in the spectra of the Cepheid variables ζ Geminorum, η Aquilae, and δ Cephei have been continued by Adams and Joy. The velocity-curve for the first of these stars is nearly completed.

Thirty-seven spectrograms of Arcturus by Adams with the coudé spectrograph have yielded a solar parallax of $8\overset{m}{.}805 \pm 0\overset{m}{.}007$.

SPECTRA OF VARIABLE STARS

Variables of the SS Cygni class are of exceptional spectroscopic interest because of their recurrent nova-like outbursts in semiperiodic cycles. Observations are difficult because of faintness and irregularity in light-variation. Six stars of this class have been observed by Joy; at maximum of light two show only a continuous spectrum; three, a continuous spectrum with undisplaced emission lines of hydrogen 10 angstroms wide; while the remaining star, SU Ursae Majoris, shows emission lines both of helium and of hydrogen on a continuous background. At minimum of light, however, absorption lines corresponding to those of type dG₃ appear in the spectrum of SU Ursae Majoris, and the emission lines are strengthened. This observation indicates that these stars are dwarfs, the only known stars of low luminosity with intrinsic variability.

Joy has also observed the spectra of a large number of variables with intermediate or irregular periods, several eclipsing variables, and Cepheid variables in the globular star clusters M 2, M 3, M 10, and M 12.

Several observers have studied special features of the spectra of long-period variables. Merrill has given particular attention to the

molecular bands in the visual region of some typical variables at various phases of light, more especially the monoxides of *Ti*, *Zr*, *V*, *Sc*, and *Y*. Joy has continued his observations of the character and changes of the emission lines in the spectrum of o Ceti; and Adams, using the high dispersion of the coudé spectrograph on this star when near maximum, has examined the structure of some of the bright hydrogen lines and has measured the displacements of absorption lines of various classes. A definite correlation seems to exist between radial velocity and the lower excitation level of the lines involved. The doubling of numerous absorption lines characteristic of supergiant M-type stars has also been found in the spectrum of o Ceti.

An important contribution to our knowledge of this class of stars is the monograph by Merrill on "Spectra of long-period variable stars," which will appear in the series issued by the *Astrophysical Journal*.

BANDS IN STARS OF SPECTRAL TYPES M, N, AND R

Closely associated with studies of long-period variables has been the investigation by Miss Dorothy Davis of molecular bands in the spectrum of the bright M-type star β Pegasi. High-dispersion spectrograms have made it possible to study this star in great detail, and the wave lengths of about 5800 lines have been measured in the region $\lambda 3780-\lambda 6780$. Visual estimates of intensities have been completed and identifications have been established for many molecular lines and bands. These include, roughly in order of strength: *TiO*, *SiH*, *MgH*, *AlH*, *ZrO*, *ScO*, *BO*, *SiF*, *SiN*, *CH*, and *CN*. Some of these have been identified for the first time in stellar spectra.

Sanford has found evidence for the presence in N-type spectra not only of bands due to the carbon isotopes $C^{12}C^{13}$ and $C^{13}C^{13}$, but also of bands of $C^{13}N^{14}$, analogous to the $C^{12}N^{14}$ bands. In the red region of the spectrum various N-type stars are found to show marked differences in the structure and strength of the Swan bands. Similar differences are shown by variables at various phases

of their light-curves. The intensities of the D lines of sodium differ by a factor of 25 in various stars. A set of bands not previously identified seems to agree in position with bands given by metallic *Ca* in the electric furnace and may possibly be due to *Ca₂*.

Be STARS

Numerous additional stars of early type with emission lines have been discovered on photographs made by William C. Miller with the 10-inch telescope and objective prism. These are being investigated with slit spectrographs by Merrill and Miss Burwell, and the results will be incorporated into a supplement to the "Catalogue and bibliography of stars of classes B and A whose spectra have bright hydrogen lines," published in 1933.

ζ AURIGAE

This remarkable star was observed extensively by O. C. Wilson at its eclipse in 1939–1940, particularly during ingress. About 60 spectrograms were obtained with the 32-inch Schmidt camera of the coudé spectrograph and about one-fourth of these have been traced with the microphotometer. Curves of growth have been derived for various levels in the star's atmosphere, and the turbulence and the excitation temperature, calculated for four and three levels, respectively, are found to increase outward from the photosphere. Ultimately it should be possible to derive the electron pressures and the total density with fair accuracy.

The light-curve of ζ Aurigae was observed by Christie throughout the eclipse, and its form seems to be well established.

INTERSTELLAR LINES

Several investigations have dealt with the lines due to the absorption of gases in interstellar space. In the course of one of these Sanford has found that the star HD 190429 N, which shows double interstellar H and K lines, has single D lines, thus indicating a marked difference in the distribution of ionized calcium and neutral sodium gases along the line from the sun to the star.

The interesting problem of the concentration of ionized calcium gas in the neighborhood of the sun has been studied by Dunham through measurements of the intensity of the interstellar K line in the spectra of some of the nearest early B-type stars. Spectrograms on fine-grained plates were made with the 114-inch camera of the coudé spectrograph. A faint interstellar line was measured in the spectrum of α Virginis, which has a distance of the order of 55 parsecs. The indicated concentration of $Ca\text{ II}$ is 3×10^{-10} ions per cubic centimeter. No line could be detected in η Ursae Majoris, at a distance of about 65 parsecs. The concentration must differ by a factor of at least 2 along the paths to these stars, although the mid-points of the paths are separated only some 30 parsecs. This indicates that the distribution of interstellar material is extremely irregular even over short distances. The value for the density of $Ca\text{ II}$ is much less than that found by Merrill and Sanford for distant stars in the general direction of the Milky Way.

Among the unidentified interstellar lines discovered a few years ago at Mount Wilson is a prominent line at $\lambda 4300.3$. The suggestion was made by Swings and Rosenfeld that it might be due to the molecule CH , but no satisfactory identification could be based upon a single line. Recently McKellar, assuming $\lambda 4300$ to be due to CH at very low temperatures, predicted the presence of three fainter lines, and calculated their relative intensities. All four lines arise from the ground electronic state of the molecule and are the only ones sufficiently strong to present some possibility of observation as interstellar lines.

Although the three predicted lines had not been observed in any stellar spectrum, it seemed possible that they might appear on a reasonably fine-grained plate of sufficient contrast. Fortunately a bright star, ζ Ophiuchi of magnitude 2.7, in which $\lambda 4300$ is prominent, was available. Spectrograms taken by Adams with the 114-inch coudé spectrograph showed three lines close to the predicted positions and with the proper relative intensities. Measurements of wave length gave an aver-

age difference from the laboratory values of 0.03 \AA , a quantity well within the accuracy of the determinations. The agreement of the four lines in wave length and relative intensity, and the fact that only those lines appear as interstellar lines which should be present on the basis of theoretical considerations, afford conclusive evidence of the correctness of the identification of CH . This confirmation of McKellar's prediction provides the first definite evidence of the existence of molecules in interstellar space.

The situation regarding the identification of CN is of equal interest. Two lines listed by McKellar at $\lambda 3874.0$ and $\lambda 3874.6$ are certainly present as interstellar lines with wave lengths agreeing closely with the laboratory values. Two other very faint lines have been measured at $\lambda\lambda 3579.98$ and 3875.78 which also agree closely with two faint lines predicted by McKellar at $\lambda\lambda 3579.98$ and 3875.77 . The evidence for the presence of interstellar CN is, therefore, essentially as conclusive as that for CH . As McKellar has pointed out, the presence of the line $\lambda 3874.0$ is especially interesting since it arises from the $R(1)$ rotational level as compared with the $R(0)$ level of $\lambda 3874.6$. The difference amounts to 0.00047 volt, and the relative intensities of the two lines afford a means of calculating the actual "effective" temperature of interstellar space. This is about $2^{\circ}5$ on the absolute scale.

The spectrograms of ζ Ophiuchi show a previously unobserved line of moderate intensity at $\lambda 3745.3$ and also close interstellar components to the prominent interstellar H and K lines of calcium.

MICROPHOTOMETRIC STUDIES OF STELLAR SPECTRA

Tracings of spectra made with the microphotometer have been used to great advantage in nearly all the stellar investigations. The high-dispersion spectrograms taken with the coudé spectrograph are being used by Dunham and Miss Carlson in studies of line intensities and contours in the ultraviolet region. Especial attention has been given to the spectrum of α Cygni.

GALACTIC NEBULAE

R AQUARI

Hubble reports that comparisons of direct photographs, over an interval of 17 years, show definite changes in the nebulosity surrounding R Aquarii. Outward motion is evidently involved, but its precise nature is not yet clear and will be investigated further.

EXPANSION OF THE CYGNUS LOOP

Angular motions in the great loop in Cygnus (NGC 6960-6992) have long been

observed, and have been interpreted as expansion of the loop. An attempt, by Humason, to determine the linear velocity of expansion, using small-scale spectra, was unsuccessful. He has now repeated the investigation, using several spectrograms of considerably larger dispersion, but the results are again negative. They suggest, as a conservative conclusion, that the velocity of expansion is definitely less than 100 km/sec. The corresponding distance, indicated by the angular expansion, appears to be less than 300 parsecs.

EXTRAGALACTIC NEBULAE

SPECTRA OF EXTRAGALACTIC NEBULAE

Spectra of nearly 300 nebulae are now available at Mount Wilson, the great majority having been obtained by Humason. Most of these spectra are on a small scale (500 or 1000 Å/mm at $H\gamma$) and, while they have served admirably for the preliminary survey of a new field, they have permitted the recognition and study of only the more conspicuous phenomena (law of red shifts, velocity dispersions in clusters, etc.). Emphasis has now shifted from surveys to special problems. Some of these problems must necessarily be investigated with small-scale spectra, but others are assuming an importance which requires much larger scales.

The practical aspects of the new problems have been explored during the year, with large-scale spectra of M 31, M 32, and M 33, intermediate-scale spectra (175 Å/mm at $H\gamma$) of 22 nebulae of various types, and a few grating spectra in the red. The results have led to the formulation of an extensive program which will be carried out with the new, recently completed spectrograph which gives dispersions of 40 Å/mm and upward at $H\gamma$. This instrument and the small-scale spectrograph for use at the Newtonian focus are described briefly under "Stellar spectroscopy."

CONFIRMATION OF A LARGE RED SHIFT

Humason has obtained an important spectrogram of a faint nebula in the Boötes

cluster which, in a typical case, fully confirms the identification of details previously made on a plate of very small scale. The nebula, $m_{pg}=17.8$, had been observed with a wide slit and a dispersion of 1000 Å/mm at $H\gamma$, the nebular spectrum being superposed on the sky spectrum. The new exposure, obtained with a narrow slit and double the former dispersion, materially improves the definition, and suppresses the sky spectrum. Four features can be definitely identified, the G band, H and K, and the complex band $\lambda 3830 \pm$. The measured displacements, corresponding to a velocity of +39,000 km/sec, confirm the value previously derived from the small-scale spectrum, and definitely establish an extreme point on the velocity-distance curve. The result inspires greater confidence in the identification of details in all the earlier spectra with large red shifts.

The new spectrum records some of the more conspicuous emission lines of mercury, which presumably originate in the valley lights. This effect has been increasing in late years, and is now generally found on all spectrograms with long exposures.

MISCELLANEOUS RESULTS

Humason has also successfully recorded the spectrum of an extremely faint emission patch in IC 1613 (a member of the Local Group), and has investigated the spectrographic rotation of the typical E7 nebula NGC 3115, on a considerably larger scale than that previously employed.

MASSES OF NEBULAE

Investigations of two unsolved fundamental problems, namely, the order of nebular masses and the direction of rotation in spirals, were initiated during the year. Statistical masses may be derived from radial velocities of components of double nebulae by familiar methods used in the case of double stars, and, over a period of years, Humason has been assembling the requisite data. Hubble has now analyzed these data and finds that the masses are so small that the mass effects cannot be isolated from the uncertainties of the velocities. The results suggest an upper limit of the order of 10^{10} suns. A new program has been initiated by Hubble and Humason for the purpose of assembling more precise velocities. The first 10 pairs observed seem to confirm the low order of mass suggested by the less accurate velocities.

ROTATION OF NEBULAE

The problem of the direction of rotation requires spectrographic observation of nebulae in which the spiral patterns can be traced and the direction of the tilt can be unambiguously determined. Such cases are very rare, but, after a complete survey of the 1000 brightest nebulae in the northern sky, Hubble has now found three objects which seem to meet the specifications. He has already observed the spectrographic rotation in one case, NGC 4258 (the arms appear to trail behind as the spiral rotates), and the other objects will be observed during the coming season.

DWARF IRREGULAR NEBULAE

Increasing evidence that absolutely faint irregular nebulae of the Magellanic Cloud type are characterized by low surface brightness and small color index suggests the possibility of using these criteria for locating such dwarf systems. Baade has tested the suggestion by examining with the 100-inch telescope a list of possible cases assembled by Zwicky with the 18-inch Schmidt reflector on Palomar. Two of the objects, both uncatalogued,

prove to be highly resolved, near-by, irregular systems, and, intrinsically, the faintest known of the extragalactic nebulae. The 1940 positions, the moduli (derived from the brightest stars), and the absolute magnitudes are shown in the accompanying table.

	R.A.	Dec.	$(m - M)$	M_{pg}
Sextans.....	10 ^h 8 ^m 1	- 4° 24'	22.7	- 10.0
Leo.....	9 55.9	+31 2	22.9	- 8.7

CLASSIFICATION OF NEBULAE

The classification, on large-scale reflector plates, of the 800 Shapley-Ames nebulae brighter than the 13th magnitude, and north of -30° declination, has been completed by Hubble, and considerable progress has been made in the quantitative analysis of their characteristics. In addition, some 200 other nebulae, either slightly fainter than the 13th magnitude or south of -30° declination, have been classified as a supplement to the main sample collection. An examination of the small-scale distribution is under way, including the relative frequencies of groups of different populations. It appears that isolated nebulae are relatively rare, the percentages ranging from about 5 among elliptical nebulae to 15 among late-type spirals.

STRUCTURAL FORMS OF NEBULAE

Randers has examined the structural forms of nebulae from a hydrodynamical point of view. The great variety of types which differ fundamentally from both normal spirals and elliptical nebulae indicates that current theories of the formation of spiral arms by the ejection of matter from rotating lenticular nebulae are not sufficient for an explanation of nebular evolution. The patterns of circular rings and systems of rings, found in spirals as well as in the so-called "transitional" type, may be an important step in the evolution. The active agent in the formation of rings appears to be viscosity in a differentially rotating system.

DISTRIBUTION OF NEBULAE

Holmberg has made the first quantitative measures of the clustering tendency of nebulae from their observed distribution in the sky. By an analysis of angular distances between nebulae in the General Catalogue and the Shapley-Ames Catalogue, he has made a statistical separation between physical and optical companions and has determined dimensions and relative frequencies of groups with different numbers of components.

The observed grouping, from an evolutionary point of view, might represent a stage in either the formation or the disintegration of clusters. Holmberg has examined the former alternative in detail. Assuming average masses of the order of 10^{11} suns, average space velocities of the order of 320 km/sec, and effective capture distances of 4000 parsecs, he finds that a process of clustering by capture from an originally random distribution of nebulae in a stationary universe would lead to a distribution similar to that actually observed, in a period of the order of 2×10^{12} years. The assumptions would also account for the observed numbers of high velocities, ascribing them to temporary members of the clusters.

A structural evolution along these lines does not seem likely in a rapidly expanding universe unless the expansion is assumed to be of a very irregular nature.

SPECTRA OF SUPERNOVAE

Minkowski has observed the spectra of the three supernovae discovered during the year in NGC 6942 (No. 2), 5907, and 4725, and, in the last two, has recognized a new type of supernova. These objects are provisionally called "type II," and those previously investigated "type I" (represented, for instance, by the supernova in IC 4182).

The type II object in 4725 is unusually well observed, having been followed closely for about four months after maximum. Up to six days after maximum the spectrum was continuous, having high intensity in the blue,

with no visible structure other than suspected emission near $H\alpha$. Thereafter, the continuous spectrum faded, and broad emission bands developed which, from about three weeks after maximum, continued to dominate the spectrum. Some of the bands are evidently complex, and the great width of the individual bands (velocities of 5000 km/sec or more on the assumption of expanding shells) renders complete identification difficult. However, the spectrum as a whole resembles that of normal novae in the transition stage, although the hydrogen bands are relatively faint and forbidden lines are either extremely faint or missing.

Supernovae of type II differ from those of type I in the transition from a continuous spectrum at maximum to an emission spectrum whose main constituents can be readily identified. As compared with normal novae, supernovae of type II show a considerably earlier type of spectrum at maximum, and hence a higher surface temperature (order of $40,000^\circ$); and the later emission spectrum indicates greater velocities of expansion and higher levels of excitation.

The obvious suggestion that supernovae of type II are intermediate between ordinary novae and supernovae of type I will be investigated.

LIGHT-CURVES OF SUPERNOVAE

Baade has derived light-curves of the five supernovae in NGC 4621, 4636, 6946 (No. 2), 5907, and 4725. The curves of the first three are similar to the normal curve representing most of the supernovae previously investigated. The two objects of Minkowski's type II, namely, those in NGC 5907 and NGC 4725, are abnormal in showing a conspicuous shoulder in the light-curve following maximum. On the basis of this criterion, Baade has added the supernovae in 4273 and 5236 to the new group. These four objects, at maximum, were systematically fainter than those of type I, averaging less than $M_{pg} = -12$.

LABORATORY INVESTIGATIONS

FURNACE AND ARC SPECTRA

The study of the spectrum of gadolinium, including segregation of the *Gd I* and *Gd II* spectra, measures of wave length, intensity estimates, and temperature classification, has been continued by A. S. King, with much assistance in wave-length measurement by E. F. Adams. The present list, subject to checking and probable extension in the infrared, contains nearly 6000 lines. Supplementary spectrograms made during the year have been chiefly in the ultraviolet, where absorption furnace spectra show low-level lines beyond the limit of emission spectra, and in the infrared. A more exact measurement of the numerous faint lines needed in the completion of multiplet structure is the chief work remaining.

The temperature classification of the stronger *Gd I* lines was used by Russell, in collaboration with Dr. Albertson, of the Massachusetts Institute of Technology, in beginning a term analysis which has brought out the main features of the spectral structure. The triad of PDF terms of multiplicity 11, and the high ${}^{11}\text{D}^0$ term with which they combine, have been found. This is the highest multiplicity which is theoretically to be anticipated in any spectrum.

A further study of titanium oxide and carbon bands has been made by A. S. King, including the conditions for the appearance of bands due to the isotope C^{13} . Numerous additional photographs of the arc and furnace spectrum of scandium have been made, with an extension into the infrared beyond the range already studied. The considerable amount of this rare substance available has made it possible to obtain spectrograms of such intensity as to add materially to the lines previously known.

MEASUREMENT OF *f*-VALUES

The measurement of the relative and absolute *f*-values of spectral lines by the method of total absorption has been continued by R. B. King. In addition to values for lines of

Cd I and *Cu I* previously reported, the absolute *f*-values have been obtained for the *Tl I* lines $\lambda 3776$, $\lambda 5350$, and for a number of lines belonging to two multiplets arising from the normal $a^5\text{D}$ state of *Fe I*. The latter will serve to place on an absolute scale the more extensive *f*-values for *Fe I* lines derived from measurements of absorption and emission spectra. The measurement of relative *f*-values for lines in the spectra of *Ni I* and *V I* has been continued.

The accurate control of temperature and vapor pressure in the furnace over the wide range used in measurements of absolute *f*-values has permitted a rather detailed study of the whole course of the curve of growth of the absorption lines *Cd* $\lambda 3261$ and *Tl* $\lambda 3776$.

INTENSITY MEASUREMENTS OF EMISSION LINES OF IRON

Through a study of the conditions under which accurate photometric treatment of emission lines of iron can be carried on, Minkowski and R. B. King have found that, if the pressure in the furnace is lowered to 20 mm of mercury or less, considerable variation of the relative intensities in at least two multiplets can be observed. The nature of the deviations from thermodynamical equilibrium which are responsible for these variations has not yet been established definitely. At least one of these multiplets ($a^5\text{F}-z^5\text{D}^0$) seems to show differences of relative intensities of a similar type in the spectra of certain stars. At higher pressures purely thermal excitation of emission lines is obtained. The results for relative *f*-values of emission iron lines are in excellent agreement with the values obtained by R. B. and A. S. King from absorption lines. The measurements will now be extended to lines of higher excitation which are not accessible as absorption lines.

EXTREME ULTRAVIOLET SPECTRA OF GASES

A study of the absorption spectra of hydrogen and rare gases in the region of the extreme ultraviolet was made by Takamine and

Tanaka, using a vacuum spectrograph provided with a 20-cm concave grating at grazing incidence. That the helium continuum between $\lambda 500\text{ \AA}$ and $\lambda 900\text{ \AA}$ is of molecular origin was indicated by its absence in absorption even at fairly high pressures. The Lyman series of hydrogen was obtained in absorption up to its eighth member. For neon, most of the lines belonging to the resonance series were seen as absorption lines, and in the case of helium, the broadening of the resonance line $\lambda 584\text{ \AA}$ was found to be quite similar to its structure in emission.

RULING MACHINES

The driving connection for the plate carriage and the operating nut of antifriction metal have been completed for the small machine and ruling tests show that these parts, together with the new screw, are functioning satisfactorily. With the suppression of the larger errors, the smaller ones of the

accidental type are seen to be related to one of two or three independent causes which may operate simultaneously. The remaining errors of the periodic type are located in the spacing gear. Ghosts arising from these are unimportant in the first order but are undesirably strong in the third and higher orders. Through an extension of the method already used for removing larger errors from the gear these ghosts can doubtless be reduced greatly in intensity.

Films of evaporated duralumin (*Al, Mg, Cu, Mn*) have been found superior in some respects to those of pure *Al*, as they tear less easily and adhere more firmly to the glass. Through the generosity of Professor Planiol (Ecole Normale Supérieure, Paris), a few diamonds from the Dutch East Indies have been presented to the Observatory. These are considered by expert judges to be harder than any other known diamonds; and they are proving most valuable as ruling tools.

CONSTRUCTION AND MAINTENANCE

DESIGN AND INSTRUMENT SHOP

Two major instruments, completely designed during the year and later placed under construction in the instrument shop, have been the new two-prism spectrograph for use at the Cassegrain focus of the 100-inch telescope, and the 10-inch photovisual telescope. The spectrograph has been completed and placed in use. The reconstruction of the equipment for the 60-foot tower telescope has also been finished. Other important apparatus has included the mounting for the 36-inch mirror of the coudé spectrograph, a new drive for the 20-inch telescope, a scanning comparator, new parts for the interferometer spectrograph, and the mirror cells and some other portions of the large eclipse spectrograph. Repairs and improvements to existing instruments have required about 20 per cent of the time of the instrument shop.

E. C. Nichols, assisted by H. S. Kinney, has been in charge of design, and Albert McIntire has supervised the work of the instrument shop.

OPTICAL SHOP*

John S. Dalton and Donald O. Hendrix have carried on the optical work, completing the figuring of numerous prisms and lenses and two plane mirrors, each about 20 inches in diameter. Much of the difficult work of figuring the components of the 10-inch photovisual lens has been finished by Dalton. Hendrix has developed most successfully methods for controlling the deposition of evaporated films upon optical surfaces to reduce loss by reflection, and has applied them to most of the optical parts of the stellar spectrographs.

By special arrangement with the California Institute of Technology, the 72-inch spherical mirror $F/2.5$ for the 48-inch Schmidt telescope on Palomar Mountain has been figured in the Observatory optical shop. The entire work of grinding and polishing was completed by Hendrix and Dietz in 21 weeks. The difficult task of figuring the 48-inch correcting plate for this instrument will soon begin.

BUILDINGS AND GROUNDS

The reconstruction of the 60-foot telescope during the summer of 1939 involved moving the tower a distance of 4 feet and considerable new structural steel and concrete construction. This work was done under the superintendence of A. N. Beebe. The complicated system of electric wiring for the instrument

was installed completely by Sidney Jones, engineer, and Kenneth De Huff, assistant engineer. The 60-foot tower and the dome of the 6-inch telescope have been repainted with aluminum paint and many small repairs have been effected.

In Pasadena all the main buildings have been repainted.

THE LIBRARY

During the past year 269 volumes have been added to the library, 55 by gift, 63 by purchase, and 151 by binding, making a total of 14,301 volumes, with about 12,000 pamphlets and 2500 lantern slides. The amount of material received from the 200 observatories

and research institutions which ordinarily send their publications to the library has been greatly reduced this year. Also because of war in Europe the number of periodicals usually received has dropped from 134 to 110, of which 34 are gifts or exchanges.

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SPECIAL PROJECTS: ASTRONOMY

S. A. MITCHELL, University of Virginia. *Astronomical studies at the Leander McCormick Observatory.*

In addition to the funds from the Carnegie Corporation of New York made available through the Carnegie Institution of Washington, referred to in Year Book No. 38, for the erection of a 10-inch Cooke camera, small grants have been made by the Corporation to support research activities undertaken with the 10-inch and also with the 26-inch refractor.

The research work of the Leander McCormick Observatory is centered around the latter instrument, at one time the largest telescope in existence. Although it is a visual refractor, practically all the work is done by photography. The chief interest is in positional astronomy. During 1940, volume 8 of the "Publications," consisting of 750 pages, has been distributed. The volume is entitled *The trigonometric parallaxes of 650 stars*, and contains also a discussion of 1350 parallaxes determined at the Leander McCormick Observatory.

In spite of the great advances of recent years in the determination of stellar distances by spectroscopic and other methods, the trigonometric parallaxes are the only ones directly observed, and all other stellar distances must be calibrated or standardized by the trigonometric values. In *The masses of the stars* (p. 60, 1940), by H. N. Russell and C. E. Moore, there appears the statement: "For the giants, however, there is a very serious difference between the mean reduced trigonometric and spectroscopic parallaxes. This arises from the parallaxes themselves." In order to make more certain the information from the trigonometric parallaxes, at the request of Dr. Adams of the Mount Wilson Observatory, the McCormick Observatory has put on its observing program about 70 giants of late spectral types. Up to date, the McCormick Observatory has completed the trigonometric parallaxes of 570 stars of K and M types.

Proper motions of high accuracy are derived at the McCormick Observatory by comparing measurements from early and late photographs taken with the 26-inch refractor. This proper-motion work yields mean parallaxes of groups of stars whose distances are too great to be measured by the annual parallactic displacements. Groups under investigation include: (1) stars of each magnitude from 8th to 12th in various galactic latitudes, (2) 10th- and 11th-magnitude stars grouped according to spectral class and galactic latitude, (3) stars in dark and in bright portions of the Milky Way, (4) Cepheid variables, and (5) long-period variables. Mean distances may be obtained from proper motions by two independent methods: we may compare their average peculiar motion with the known average space velocities of brighter stars, or we may compare the apparent drift of the group as a whole with the sun's velocity which occasions this drift. This second method yields, in addition to the mean distances, the position of the apex of the solar motion with respect to each group.

Likewise, this proper-motion work yields such valuable items as the constants of the precessional motion of the earth's pole around the pole of the ecliptic, together with a determination of the constants characterizing the rotation of the galaxy. The proper-motion work further gives a determination of the constants of the velocity ellipsoids of various groups of stars, and also gives information on the concentration of various types of stars toward the galactic plane.

In 1937, in McCormick Observatory "Publications," volume 7, there was a discussion of 18,000 proper motions distributed in 341 regions of the sky. A second investigation of the same type is now in progress in order to give additional information and to clear up some doubtful points. The second publication will include 12,000 additional faint stars in

440 regions of the sky. As of June 30, 1940, the motions of 10,000 of these stars in 368 regions have been measured. The experience gained from volume 7 has caused certain modifications in the procedure, with the result that stars fainter than the 12th magnitude and within 1 cm. of the edge of the plate are not measured. As a result of the omission of these faint stars with greater accidental errors of measurement, the stars of the second proper-motion investigation will have fewer stars per region but a relatively higher weight.

In the first investigation there were a total of 5200 stars with known spectra, but in the second investigation there will be 7500 stars with spectra. Up to the present, 5500 stars of the second investigation have been assigned spectral types.

In 1926, the Mount Wilson and the McCormick Observatories inaugurated a cooperative research on the Cepheid variables in order to determine the zero point and scale of the period-luminosity law. The plan called for proper motions to be determined by photographs with the 60-inch Mount Wilson reflector and independently with the 26-inch McCormick refractor, and also for radial velocities to be determined at Mount Wilson.

To insure the highest accuracy in the radial

velocities it was unnecessary for a time interval to elapse as in the proper-motion work, and accordingly the line-of-sight motions have already been published by Joy. For the Cepheid problem a higher accuracy is required than for the other McCormick proper-motion investigation, with the result that two pairs of plates, each with two images, are being measured instead of one pair. The McCormick measures now proceeding show a satisfactorily high accuracy represented by an internal probable error of 0''.0022 in the annual motions. The reference frames of stars are chosen after inspection of the spectral plates. Where possible, 20 stars of early types and of 10th or 11th magnitude are selected. As the photographs are measured both in right ascension and in declination coordinates, the amount of measurement involved in the McCormick method of determining the proper motion of one Cepheid variable is considerably greater in amount than the measurement required for one trigonometric parallax.

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GEOPHYSICAL LABORATORY

Washington, District of Columbia

L. H. ADAMS, *Director*

The ultimate goal of the science of geology is a complete description of the distribution of terrestrial matter in time and space. When we go beyond the descriptive stages of this science and seek a fundamental basis for an understanding of the complex processes that have given to the Earth its present gross and detailed structures and even now are remolding its surface and convulsing its interior, we find ourselves in the domains of physics and chemistry. Indeed, we get into the difficult and undeveloped regions of these sciences where it is necessary to examine the behavior of recalcitrant substances under conditions of temperature and pressure that strain to the limit the possibilities of laboratory technique. The development of this physicochemical aspect of geology has been the objective of the Geophysical Laboratory since its foundation. The Laboratory is, therefore, one unit operating in the ever advancing front line of the sciences of physics, chemistry, and geology, and as such it attains its highest usefulness when its activities combine judiciously a long-range systematic attack on the refractory problems in its field with an alertness to recognize and an adaptability to take advantage of recent advances in other sectors of the front and, in return, to use its own peculiar resources, both tangible and intangible, to open up new fields for exploitation by workers in neighboring sectors. Although such considerations pertain in a greater or less degree to all scientific research, they are peculiarly applicable to the program of the Geophysical Laboratory on account of the broad scope of its problems. The adherence to these general principles may perhaps be illustrated by the following outline of some of the results obtained during the past year. Because the attitude of a modern research laboratory is really more akin to that of a division in an army actively engaged in operations over a wide front than to the ruminative and lei-

surely outlook so often associated with traditional scholasticism, it will be convenient, in the delineation of these results, to borrow certain military phrases of well-known connotation in order to emphasize the relation of the various investigations to the Laboratory's general objectives.

Siege problems. It has long been recognized that organizations devoted to pure research can render a distinct contribution to the general advance of science by undertaking siege problems, that is to say, strategic and sometimes formidable problems whose subjugation requires the long-continued application of specialized techniques, generally with the compilation and interpretation of copious data. Such operations may not always yield newsworthy results, but they represent consolidated advances into rich regions which not only are valuable in themselves but also afford bases for theoretical and industrial advances in other directions.

The Laboratory's chief activity of this type has been the investigation of the genesis of rock-forming minerals by a systematic study of the temperatures at which synthetic minerals are in equilibrium with molten mixtures of known composition. The results are systematized according to phase rule methods and are presented as equilibrium diagrams, from which the complete course of crystallization of mixtures of a given set of substances, commonly called a system, may be deduced.

The past year has seen the successful occupation of two extensive portions of this front by the completion of the two fundamental oxide systems, *potash—alumina—silica* ($K_2O-Al_2O_3-SiO_2$) and *soda—alumina—silica* ($Na_2O-Al_2O_3-SiO_2$). These results have a direct bearing on the formation of the geologically important minerals leucite, potash-feldspar, albite, and nepheline, and show the course of crystallization of these minerals when excesses of their component

oxides are present in the molten mixtures. Because of the complexity of the natural magmas and the variability in composition of natural minerals, studies on these fundamental systems are more directly applicable to mineral formation than are equilibrium diagrams of systems whose components are compounds of ideal mineral compositions. A knowledge of the chemical behavior of these two systems is essential in an attack on the problems of the latest stages in the crystallization of igneous rocks on account of their relation to the system *kaliophilite-nepheline-silica* ($KAlSiO_4$ — $NaAlSiO_4$ — SiO_2), the "residua" system of petrology, and because they give the fundamental basis from which to launch an attack on hydrous systems that bear directly on pegmatite formation and the hydrothermal alteration of minerals.

Several other anhydrous systems involving rock-forming minerals have been completed during this year. One of these is the system *ferrous oxide-alumina-silica* (FeO — Al_2O_3 — SiO_2), which not only is of considerable geological interest because of the information it gives concerning the crystallization of the minerals olivine, hercynite, mullite, and corundum, but also is immediately applicable to various metallurgical processes and to the production of refractories and other ceramic materials.

Another "siege" problem in the Laboratory's program depends for its basis of attack on the advances made in the work to which reference has been made. This problem concerns the effect of water on the crystallization of minerals from melts consisting of alkalis, alkaline earths, alumina, and silica. It is now well established that after a molten magma has deposited the greater proportion of its crystalline minerals it is relatively rich in volatile materials, of which water is the most abundant. The presence of these volatile materials modifies the course of the crystallization that would be expected from a study of the anhydrous melts. Moreover, the water and other volatiles, on escaping from the magma, may, by their transport of heat and chemical activity, produce extensive alterations in the colder surrounding rock and, by

their mobility, lead to the segregation of economically valuable materials as ore deposits. The strategic importance of such a problem is evident, and justifies continuing effort despite the difficulties that arise from the necessity for combining a high-temperature with a high-pressure technique and for overcoming the corrosive action of the volatile constituents. Among the results obtained during the year, one of special significance was obtained during the investigation of the action of water under a pressure of 200 atmospheres on molten mixtures of soda, lime, and silica. Under these conditions the field of chemical composition in which the compound devitrite ($Na_2O \cdot 3CaO \cdot 6SiO_2$) is stable is considerably reduced, by the extension of the fields of stability of silica, on the one hand, and of the metasilicate $Na_2O \cdot 2CaO \cdot 3SiO_2$, on the other. Because of the analogous (but not identical) chemical structures of devitrite and feldspars and of the metasilicate and a basalt, a study of the effect of water on this compound has a direct bearing on the possibilities of similar effects during the formation of natural rocks.

Reconnaissance problems. Present-day igneous activity, as seen in the volcanic and hot-spring areas of the world, occupies a prominent place in the Laboratory's program, partly because of the importance of understanding and predicting volcanic activity, and partly because of the conviction that what is happening in volcanic areas today is closely related to what happened in the past when the rocks of the Earth's crust were solidifying. Although significant progress has been made in these studies, it should be noted that the work is still in the stage of "reconnaissance." Field studies of active volcanoes or hot-spring regions by geologists, and especially by investigators having an appreciation of the scope and limitations of laboratory experimental methods, for the purpose of locating strategic problems and planning methods of attack are operations of prime importance in this field. During the past year an expedition from the Laboratory, in cooperation with the Department of Terrestrial Magnetism, visited volcanic areas in Guatemala and succeeded in

getting into closer touch with some of the very active centers than has been possible in the past. A new group of hitherto inaccessible fumaroles was reached, the chemical activity examined, temperatures measured, and specimens for laboratory study collected. It was found possible to study at close range the extrusion of lava from Santiaguito, the active region of the volcano Santa María, observe the temperatures, and obtain an improved conception of the nature of the lava.

Of recent years many instruments have been developed for making observations from which inferences concerning subterranean conditions may be drawn; it is *a priori* highly probable that these techniques will yield valuable information concerning volcanic regions. In the course of the cooperative studies a start was made on the determination of gravity at significant locations in Guatemala, a series of electrical resistivity measurements over large pumice deposits were made, observations of Earth tremors with portable seismometers were carried out in the vicinity of volcanoes, and the use of buried microphones as practiced by F. A. Perret in Martinique was tested in the region near Santa María. A great part of the data of these observations has not yet been analyzed, but one important piece of progress made by the expedition was a partial bridging of the wide and unpredictable gap between the development of instruments and their use under the unfavorable conditions encountered in volcanic regions.

Expeditionary problems. The combination of reconnaissance work with systematic studies gives a self-contained type of investigation that has its analogue in the military expedition. This is illustrated by the work on the radioactivity of sediments on the ocean floor. By means of an apparatus developed in the Laboratory, it is now possible to collect, from almost any depth in the ocean, core samples of the sediments between six and ten feet long in which the vertical distribution of sediment in the natural deposit is preserved. As previously reported, a number of these samples have been collected in the Atlantic Ocean and Caribbean Sea.

With the aid of a semiautomatic apparatus developed for the purpose, rapid and precise measurements of the radium content of samples taken systematically from different parts of the cores of sediment have been made. The results form a typical example of the value of systematic measurements. In three cores, taken from regions of low latitude, it was found that the radium content at the top of the sample (latest sediment) was high as compared with the average for igneous rocks, and that it increased rapidly with depth for a short distance, passed through a maximum, and finally decreased until the bottom of the core (earliest deposits) was reached. This result, which has never been predicted, could not have been obtained without the availability of long core samples, numerous measurements, and sensitive methods of radium determination. Its implications are that these sediments are so young that the radioactive equilibrium has not been reached in them, and that in the later deposits ionium is present in excess while uranium is deficient. If radioactive equilibrium has not been attained, it is possible to measure the degree of attainment at any depth within the sediment and thence to calculate from the known properties of the radioactive elements the time that has elapsed since the sample was deposited. This opens up a method of determining not only the age but also the rate of deposition (the distribution in space and time) of these sediments covering the vast areas of the ocean floor. The value of these deductions is enhanced by the development of a method whereby their validity may be tested experimentally; and work is now in progress on this phase of the problem. The heat generated by radioactive elements in the Earth's crust is an important factor in the thermal history of the Earth, and it may be noted that from this point of view the results emerging from the systematic studies give a different and presumably better picture than did results from measurements on isolated and fortuitous samples taken by other devices.

Development and proving of experimental and theoretical equipment. As we leave the surface of the Earth and go into its interior,

we find that the pressure rises very rapidly. Even in the depths of the ocean it reaches the relatively large value of 1000 atmospheres, and at the center of the Earth it has the enormous magnitude of 3,000,000 atmospheres. An understanding of the physics and chemistry of matter under high pressures is, therefore, a prime requisite for any "deliberate speculations" (to quote Robert Boyle) on the nature of the Earth's interior. Although this subject has considerable theoretical interest, the specialized technique involved and the lack of industrial stimulus has made it one of the least developed branches of physics and chemistry, and even now less than half a dozen laboratories in the world devote much attention to work with high pressures. In this phase of its work, therefore, more than in any other at present, the Laboratory is forced to forge its own theoretical and experimental artillery, and the past year has seen several noteworthy developments. One theoretical aspect of the work has been concerned with the development of a foundation for understanding the phenomena of flow and fracture in solids. In particular, the observation made at Harvard University that the strengths of solids increase rapidly when they are confined under hydrostatic pressures exceeding 10,000 atmospheres has been placed on a theoretical basis.

These theoretical results have been applied to the design and construction of an apparatus whereby the range of experimental observations under high pressure is enormously extended, a project in which the Department of Terrestrial Magnetism cooperated. The apparatus consists essentially of one pressure generator inside another. In the outer generator a pressure of some 17,000 atmospheres is produced and maintained while a carboloy piston is forced into the inner vessel, where a pressure as high as 200,000 atmospheres has been produced. It is of importance to relate that the apparatus is large enough to insure the possibility of making precise measurements of the behavior of matter under these pressures, which correspond to a depth of approximately 300 miles below the surface of the Earth.

Significant progress toward another objective in high-pressure physics has been made this year through the combination of the Laboratory's high-pressure resources and its knowledge of minerals with the technique of sensitive magnetic measurements developed by the Department of Terrestrial Magnetism. The origin of the major portion of the Earth's magnetic field is an old but completely unsolved problem. Before a satisfactory answer can be given, we must know whether it is possible or highly improbable that the magnetic field is due to the presence in the Earth of a ferromagnetic substance. It is important, therefore, to discover whether any elements or compounds of sufficient abundance geologically are ferromagnetic under the high temperatures and pressures which exist within the Earth. Generally speaking, increase of temperature above a certain point destroys the ferromagnetism of substances; the problem is therefore to determine if the rise of pressure is large enough to annul the effect of rise of temperature. Results obtained this year show that the temperature at which a spinel of the composition $\text{CdFe}_2\text{O}_4 \cdot \text{MgFe}_2\text{O}_4$ loses its ferromagnetism is raised about half a degree for each 1000 atmospheres increase in pressure. This result, although obtained at low temperatures, is a noteworthy step toward a solution of the problem. It shows that rise of pressure does offset the effect of rise of temperature in certain substances at least, and that the magnitude of the pressure effect is large enough to be significant.

Flanking operations. An understanding of the effect of pressure on physicochemical properties such as chemical reactivity, solubility, acidity, and alkalinity in systems of geological interest is also an important objective of the Laboratory. It is expedient to divide the attack on this problem into two phases: first, an investigation of the general principles governing the effect of pressure on chemical behavior in any type of system (i.e. a mixture of two or more reacting components) by a study of relatively tractable systems; and, second, an investigation of the specific factors

which characterize each system of geological interest with a view to applying the results emerging from the first phase. An essential part of the first phase, namely, molecular interaction in liquid solutions under different conditions of temperature and pressure, is being actively studied at the Laboratory. New results have given us a clearer notion of the nature of solutions and have opened up undeveloped fields in physical chemistry for exploitation by other workers.

The solutions whose behavior are of chief interest to the Laboratory are silicate melts at high pressures and aqueous solutions both at low temperatures in the depths of the ocean and at high temperatures in hot springs and in ore-depositing fluids. The phenomena encountered in these solutions are among the most complicated in all physical chemistry, a circumstance which is due in part to the peculiar spatial distribution of the molecules in these liquids. In the development of a general basis for the study of the effects of pressure and temperature on these solutions, the contributions of the various molecular interactions to the observable phenomena must be differentiated and evaluated. During the past year two promising methods of attacking this problem have been followed. The behavior of some solutions was examined under changes of pressure and temperature so combined that the volume remained constant. Under these conditions the long-range forces between the molecules are presumed to be constant and the observed changes are attributed to changes in the short-range

forces, including changes in molecular distribution. The second method involves the use of model solutions to estimate the importance of the different factors. The study of solutions of salts dissolved in glycol has thrown considerable light on the effects of changes of molecular distribution on the properties of water solutions.

The field of pressure chemistry is still so little explored that a search for qualitatively new phenomena is profitable. An examination of the effects of pressure and temperature on the absorption of light by some solutions has revealed a new effect whose further study leads to interesting speculations about the connection between the weak intermolecular actions that cause solutions to depart from ideal behavior and the strong interactions that lead to profound chemical changes.

Intercommunication. The military analogy applies also to the applications of techniques acquired in other fields of knowledge to the problems of Earth science. An interesting example is furnished by the recent results on the fluorine content of rocks and ocean-bottom samples. An easy and surprisingly accurate method for the determination of fluorine, developed recently at the University of Michigan, was applied to rock analysis at the Laboratory. The result was unexpected and of considerable significance in that it showed that fluorine is not a minor constituent of rocks, as was formerly supposed, but is commensurate in importance with chlorine both in terrestrial rocks and in ocean-bottom sediments.

HIGH-TEMPERATURE STUDIES OF ANHYDROUS SYSTEMS AND THEIR PRESENTATION BY EQUILIBRIUM DIAGRAMS

SILICATES

Systems involving the combination of early-crystallizing and late-crystallizing minerals. The course of crystallization of a mixture of silicates and oxides having a complexity approaching that of a natural magma has not yet been amenable to laboratory study, and it is highly probable that a long time will elapse before any results of practical or theoretical value can emerge from such an investi-

gation. From the study of suitably chosen systems, however, conclusions of such general validity may be drawn that their application to natural magmas seems justifiable. Among advantageous systems for intensive study are those that deposit the minerals presumed to crystallize early in the history of a natural magma, and also the minerals of much lower melting points that have appeared at the last stages of magmatic differentiation. An impor-

tant part of these studies consists in determining how the residual liquids vary in composition as the crystallization of different ternary and quaternary mixtures proceeds. Studies of the systems *leucite—diopside—silica* ($KAl(SiO_3)_2$ — $CaMg(SiO_3)_2$ — SiO_2) and *nepheline—fayalite—silica* ($NaAlSiO_4$ — Fe_2SiO_4 — SiO_2) are completed and published [Schairer, Bowen]. Experimental work on the system *leucite—anorthite—silica* ($KAl(SiO_3)_2$ — $CaAl_2Si_2O_8$ — SiO_2) was finished during the past year and is being prepared for publication. A portion of the system *nepheline—diopside—silica* has been investigated. This is not a ternary system. Work on the system *nepheline—anorthite—silica* [Schairer, Crocker], which has been in progress since 1937, may be divided into two parts: the study of the system *albite—anorthite—silica* ($NaAlSi_3O_8$ — $CaAl_2Si_2O_8$ — SiO_2), which is nearly completed; and the study of the system *nepheline—albite—silica*, which is still in a preliminary stage.

In all these, and also other systems, the residual liquids become richer and richer in the alkali-alumina silicates as the crystallization proceeds. Except for such modification as may be caused by the presence of water and other volatile materials, this result shows that the key to an understanding of the late stages in the crystallization of natural magmas lies in the alkali-alumina silicate systems.

Alkali-alumina silicates [Schairer, Bowen]. In addition to the completion of the work on the potash—alumina—silica and soda—alumina—silica systems mentioned in the introductory part of this report, further progress has been made on the system *kaliophilite—nepheline—silica* ($KAlSiO_4$ — $NaAlSiO_4$ — SiO_2). The complexity of the various phenomena encountered in this system and the length of time required for the attainment of equilibrium (approximately one month for each run in the feldspar field) makes the work very slow, but the results appear to justify the effort. During this year the preparation of homogeneous mixtures of the proper compositions for determining the limits of ternary hexagonal solid solutions of kaliophilite, nepheline, and albite has been completed.

As a part of our systematic attack on the chemistry of the alkali silicates, a paper on the system Na_2SiO_3 — Li_2SiO_3 — SiO_2 has been published, and the work on the system $K_2Si_2O_5$ — $Na_2Si_2O_5$ has been completed [Kracek].

Quaternary systems. For a long time the system *lime—magnesia—alumina—silica* has been of special interest to both the geologist and the technologist. Many important rock-forming minerals appear in this system, and numerous binary and ternary combinations of these four oxides have been studied systematically at the Laboratory during the past thirty years. In the general attack on the complete quaternary system [Schairer, Osborn], which is now being prosecuted vigorously, the previous work on many binary mixtures of lime, alumina, magnesia, and silica has been checked, generally with excellent agreement; but in some cases need for revision has been revealed, for example in the system *akermanite—wollastonite* ($Ca_2MgSi_2O_7$ — $CaSiO_3$). The subsidiary ternary system *gehlenite—akermanite—wollastonite* ($Ca_2Al_2SiO_7$ — $Ca_2MgSi_2O_7$ — $CaSiO_3$), which combines simple members of the mellite and pyroxene groups, has also been investigated and the results of experiments on the melting relations are ready for publication. Complete data have been obtained for the liquidus and for the three-phase boundaries, which determine the compositions of the solid solutions and the courses of crystallization of all ternary liquids, either with perfect equilibrium or with perfect fractionation. There is no ternary eutectic, but there is a ternary minimum with three phases coexisting in equilibrium, a liquid, a solid pyroxene ($CaSiO_3$), and a mellite (a solid solution of gehlenite and akermanite). At temperatures well below the liquidus, indeed below $1325^{\circ}C$, pure akermanite breaks up into two unidentified solids. This phenomenon, together with the behavior of the solid solutions, is being investigated further. A study of melting relations in another subsidiary system, *wollastonite—diopside—anorthite* ($CaSiO_3$ — $CaMg(SiO_3)_2$ — $CaAl_2Si_2O_8$), is almost finished.

The problem of the formation of the augites, which are among the commonest of the rock-forming pyroxenes, requires for its solution a knowledge of the behavior of mixtures containing alumina in varying amounts. The temperature—composition relations in the quaternary system *lime—ferrous oxide—alumina—silica* should shed light on the role of alumina in the augites. In the study of this system, which promises to be a long and complicated matter, a substantial start has been made by the completion of the plane *ferrous oxide—anorthite—silica*, a plane in which the important minerals silica, anorthite, hercynite, olivine, and wüstite appear. Experiments on two other subsidiary planes, *ferrous oxide—anorthite—alumina* and *ferrous oxide—anorthite—wollastonite*, are also well under way.

The system sodium oxide—boric oxide—silica (Na_2O — B_2O_3 — SiO_2). Boric oxide is known to accumulate in significant amounts during the course of crystallization of a natural magma, and it may have a considerable effect in insuring that magmatic solutions are at all times below their critical temperatures. Furthermore, the volatility of boric oxide in steam makes it potentially important as an agent in the formation of ore deposits by transport through the vapor phase. The experimental work necessary for an understanding of this system is practically finished [Morey, Ingerson]. By an investigation of the compositions varying linearly between sodium orthoborate and sodium orthosilicate and between sodium metaborate and sodium metasilicate, especially in melts containing only a small percentage of boric oxide, it was established that the fields of stability of sodium orthosilicate and sodium metasilicate are contiguous. This upholds Kracek's conclusion that no compound intermediate in composition between sodium metasilicate and sodium orthosilicate (Na_2SiO_3 and Na_4SiO_4) exists, in spite of the contentions of workers in other laboratories that there is a stable compound of the formula $3Na_2O \cdot 2SiO_2$.

In the binary system Na_2O — B_2O_3 , Morey and Merwin found, besides the orthoborate, a metaborate ($Na_2O \cdot B_2O_3$), a diborate

($Na_2O \cdot 2B_2O_3$), a triborate ($Na_2O \cdot 3B_2O_3$), and a tetraborate ($Na_2O \cdot 4B_2O_3$). Each of these has a field in the ternary system, but the field of the metaborate dominates the system. It extends across the diborate—disilicate join, and comes in contact with the field of quartz at the quintuple point quartz—sodium disilicate—sodium metaborate—liquid—vapor, at a boric oxide content of about 20 per cent. The field of quartz is thus adjacent to the fields of sodium disilicate; also probably to the fields of each of the borates in succession, and finally to the field of crystalline boric oxide.

In the region adjacent to the quartz boundary (on the liquidus surface) and centered roughly in a trough less than 10 per cent in width, at the composition of about 25 per cent Na_2O and 20 to 50 per cent B_2O_3 , melts have not been induced to crystallize, because the liquidus temperatures are so low. Mixtures poorer in sodium oxide crystallize with less difficulty until compositions very close to zero Na_2O are reached; even melts containing only 3 per cent Na_2O have been crystallized, and no difficulty was encountered with mixtures on the line joining silica to sodium tetra-borate. By extrapolation of the results for mixtures containing only small amounts of Na_2O it is hoped that information concerning the melting relations in the binary system B_2O_3 — SiO_2 may be deduced. Such an extrapolation under less favorable conditions was made in the system CaO — B_2O_3 — SiO_2 , and a check is very desirable.

TELLURIDE MINERALS

The discovery of important quantities of gold in the form of the mineral calaverite or its weathering products in the enormous heaps of discarded waste at Cripple Creek and Camp Bird Mine, Colorado, revived interest in the little-known gold and silver telluride minerals calaverite ($Au(Ag)Te_2$), krennerite ($Au(Ag)Te_2$), sylvanite ($AuAgTe_4$), petzite ($AuAg_3Te_2$), and hessite (Ag_2Te). From the chemical and crystallographic as well as the geological standpoints, these minerals present features of such interest as

to warrant considerable study. Attention has been given to the crystal structures of these minerals, which are of an unusual character [Tunell], and the investigation of the temperature—composition relations in the system tellurium—silver—gold was finished during the past year [Kracek, Ksanda]. Only two ternary compounds, corresponding to sylvanite and petzite, were found. Both decompose on melting, the former giving AuTe_2 and a liquid, the latter giving a gold—silver alloy and a liquid. There is a single ternary eutectic at approximately 330°C with the solids Te, Ag_3Te_2 , and AuAgTe_4 and a liquid of the approximate atomic ratio 35Ag: 4Au:61Te coexisting at equilibrium. A very large portion of this equilibrium diagram is occupied by the liquidus surface of the gold—silver alloy. Liquid immiscibility between Ag_2Te and Ag extends slightly into the ternary system, and none of the possible sections through the ternary system is a binary system. Copper, silver, and gold all belong to the same group in the periodic table, as do also sulfur, selenium, and tellurium. One would expect, therefore, that certain general similarities might be found in the various systems composed of these metals and non-metals. Such similarities are found in the systems of copper or silver (denoted by M) with sulfur, selenium, or tellurium (denoted by X), but the systems involving gold are exceptional. For example, highly stable compounds of the formula M_2X are well known, but the sulfides and selenides of gold are very unstable, and the only telluride of gold, AuTe_2 , melts at a low temperature.

Moreover, in all six of the $M-X$ systems there is a region of liquid immiscibility between M_2X and M , whereas AuTe_2 and Au merely give a eutectoid relation in the complete melting diagram. Gold and silver alloys form a complete series of solid solutions, but gold and silver tellurides do not enter into solid solution to any marked extent.

COPPER AND IRON SULFIDES

Work on the sulfides of iron and copper, which has an important bearing on the formation of ore deposits, is being continued [Merwin, Greig]. The extremely complicated chemistry of these systems and the exacting technique required for microscopic examination make progress rather slow. During this year Einar Jensen, from the University of Oslo, Norway, has been cooperating with Merwin and Greig in studying melting relations and transformations above 600°C in the sulfides of iron and copper that contain low amounts of sulfur, especially mixtures of FeS (pyrrhotite) and Cu_2S (chalcoite). In these mixtures much solid solution is known to exist, and, although good results have been obtained for the freezing-point curves, the effects of solid solution at lower temperatures are still obscure. Both the quenching method and the thermal analysis method have been used in this work. It is necessary to enclose the charges of the sulfides in specially designed silica-glass containers. Breakage of these vessels, owing to low-temperature transformations in the charges, and adherence of the melts to the glass are some of the principal experimental difficulties.

EQUILIBRIUM IN SYSTEMS CONTAINING WATER AT VARIOUS PRESSURES AND TEMPERATURES

SILICATE SYSTEMS

The system *water—sodium oxide—silica* ($\text{H}_2\text{O}-\text{Na}_2\text{O}-\text{SiO}_2$) has been studied under a pressure of 200 atm. of steam over a range of compositions extending to mixtures slightly richer in silica than the sodium disilicate (Na_2SiO_5)—quartz (SiO_2) eutectic [Morey, Ingerson]. The saturation curve at

this pressure runs parallel to the liquidus curve in the anhydrous system, being lower by 175°C at the composition Na_2SiO_3 and by 165°C at the composition Na_2SiO_5 . The composition of the eutectic is thus displaced in the direction of higher silica content.

The low-temperature region of the system *water—sodium oxide—lime—silica* ($\text{H}_2\text{O}-$

$\text{Na}_2\text{O}-\text{CaO}-\text{SiO}_2$), which includes the ternary eutectic sodium disilicate—devitrite ($\text{Na}_2\text{O} \cdot 3\text{CaO} \cdot 6\text{SiO}_2$)—quartz and the field of stability of devitrite, has been studied also under a pressure of 200 atm. of steam. The field of devitrite is invaded on one side by quartz and on the other by the metasilicate ($\text{Na}_2\text{O} \cdot 2\text{CaO} \cdot 3\text{SiO}_2$), with the result that an unexpected raising of the melting point in a large portion of this region is apparently produced by the presence of the water. In the regions of composition where devitrite is still stable, the melting point is lowered by the water, as would be anticipated. In the studies of the system *water—sodium disilicate—albite*, the 200-atm. isobar is more than half completed.

The results just mentioned have to do primarily with the lowering of the melting points of certain silicates by the water that they dissolve when in contact with steam under high pressure. It is of great importance to find out just how much water is dissolved by the silicate melts under these conditions; in order to do this, the charge is quenched from a temperature just above the crystallizing point. Some results have been obtained, but an unexpected and still unexplained difficulty has been encountered in that the charges lose water during the quenching and are blown up into a mass resembling a pumice. Apparently this effect is not due to known or obvious causes, and it is being further investigated, not only with a view to its elimination, but also because of its significant implications in volcanism.

SYSTEMS CONTAINING ALKALI HYDROXIDES AND CARBONATES

By means of a filter autoclave in which the solubilities of corrosive materials may be measured at elevated temperatures and atmospheric pressure [Morey, Burlew], the solubility of sodium hydroxide (NaOH) in solutions containing some carbonate has been measured over that part of the system in which NaOH is a solid phase. An average accuracy of 1 in 2000 was realized. It was found that at temperatures below about

100° C the field of NaOH is very narrow, whereas at higher temperatures it broadens rapidly. This change can be expressed in terms of the position of the curve of double saturation that represents the boundary between the fields of NaOH and of Na_2CO_3 . Along this curve the ratio of CO_2 to Na_2O is a simple exponential function of the temperature. By extrapolation of this curve of double saturation, the binary eutectic between NaOH and Na_2CO_3 has been found to lie at a temperature of 287.9° C and a composition of 81.70 per cent NaOH and 18.30 per cent Na_2CO_3 . Along any isotherm across the field of NaOH , which gives the solubility of NaOH at that temperature in solutions containing different amounts of Na_2CO_3 , the total Na_2O content shows only slight variation; therefore extrapolation of these isotherms to the limiting binary system $\text{NaOH}-\text{H}_2\text{O}$ can be performed with little loss of accuracy. This extrapolation gives values for the solubility of NaOH in pure water at intervals of 30° from 60 to 300° C. They lie on a parabola of slight curvature.

During the year gratifying progress was made on the construction of a filter autoclave in which solubilities may be measured at elevated temperatures under fairly high pressures [Burlew]. The successful construction of such a piece of apparatus is essential to the prosecution of the program of work on the effect of water on crystallization of minerals, the immediate specific problem being an investigation of the behavior of the system $\text{H}_2\text{O}-\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$, between 150 and 500° C, an extension of the investigation described in the previous paragraph. The construction of the apparatus has reached the stage at which preliminary tests can be carried out, and it has been found that the stirrer can be operated successfully at 500° C, under a steam pressure of 200 atm., the upper limits set in the original plans. This and other tests have shown that the design of the apparatus is sound, but before it can be used for routine determinations of solubility, a number of refinements and calibrations need to be made.

SOLUTIONS AT LOW TEMPERATURES AND HIGH PRESSURES

During the past year the major portion of the work in this field [Gibson, Loeffler] has been devoted to an analysis of the pressure—volume—temperature data for a series of solutions of salts in water according to the methods suggested by the previous studies on pure liquids. Ancillary studies included the measurement of pressure—volume—temperature relations for the pure liquids carbon tetrachloride, from 25 to 65° C, and ethylene glycol, from 25 to 105°, and for a series of solutions of sodium bromide in glycol from 25 to 105°, all over the pressure range 1 to 1000 atm. The thermal expansibilities, the compressibilities, the pressure—temperature coefficients, the energy—volume coefficients, and related thermodynamic quantities of all the liquids, the glycol solutions, and the aqueous solutions including water were computed at all temperatures and pressures in the experimental range. The results are summarized as follows.

Carbon tetrachloride. This liquid, whose molecules have spherical symmetry, was studied with a view to establishing the behavior of normal liquids under changes of pressure and temperature. The energy—volume coefficient decreases slightly (5 per cent over 40°) when the temperature is raised at constant volume, and the attractive internal pressure varies inversely as the cube of the volume, an observation of theoretical interest.

Water. It is well known that the molecular distribution in liquid water makes it almost unique among liquids and is such that each molecule has on an average only 4 or 5 nearest neighbors, whereas in most liquids a molecule has 10 to 12 such neighbors. This distribution arises from directed forces between water molecules, and its rapid change with temperature is reflected in many of the unusual physical properties of water. The energy—volume coefficient of water shows up the anomalous properties of this liquid in a striking way, because instead of decreasing slightly with temperature at constant volume, as in carbon tetrachloride, it increases more than 300 per cent in the range 25 to 85° C.

This effect is directly connected with the changes in molecular distribution in water, and, although it diminishes as the temperature is raised, it is large enough at 100° to indicate that water is still quite abnormal at its boiling point. A rough extrapolation shows that changes in molecular distribution become of minor importance between 150 and 200°.

Ethylene glycol. This liquid is an excellent solvent for salts. Glycol solutions have been used as models in the study of water solutions, on the assumption that the peculiarities arising from changes in molecular distribution in water are negligible in glycol, although glycol and water solutions are quite similar in other respects. The new results justify this assumption by showing that the energy—volume coefficient of glycol increases only slightly when the temperature is raised from 25 to 105° C at constant volume, the increase being less than 10 per cent as great as that observed in water. This result indicates that glycol shares to a minor extent the peculiarities of water and that the method used to calculate the attractive internal pressure of normal liquids breaks down when applied to glycol.

Solutions of sodium bromide in ethylene glycol. Before one can make any significant generalizations concerning the relation of the volume changes on mixing to the known properties of substances dissolved in water, one must know the relative contributions of the volume changes due to changes in the molecular distribution in the water (produced by the salt) and of the volume changes due to the better-known forces between the water and the dissolved molecules. On the assumption that changes in molecular distribution contribute only a small part of the volume changes on mixing in glycol solutions, four solutions of sodium bromide in glycol were examined with a view to a comparison of their behavior with that of solutions of the same salt in water. At a given temperature the energy—volume coefficients of these solutions increase somewhat as the concentration of salt rises. For a given solution the energy—volume coefficient changes very little with temperature at constant volume. Other sig-

nificant observations may be described in terms of the "apparent volumes" of the salt in these solutions, the apparent volume being defined as the volume which the salt appears to have in the solution on the assumption that the volume of the solvent remains unchanged by the process of mixing, and the apparent expansibilities, which are defined *mutatis mutandis* in the same way. The apparent volumes of sodium bromide in glycol increase with pressure and concentration, but decrease with temperature at constant pressure. The most significant result, however, is that the apparent volume of the salt remains essentially constant when the temperature rises at constant volume, indicating that in a solution where disturbing changes in molecular distribution are negligible, the apparent volume of the salt depends only on the total volume of the solution, that is, on the mean distance of separation of the molecules.

Aqueous solutions. Computations with the data for solutions of sodium chloride, sodium bromide, and lithium bromide in water over the whole range of concentrations gave the following results. The energy—volume coefficients of the individual solutions resemble those of water in that they increase greatly with temperature at constant volume. Increase of concentration of salt, however, increases the magnitude of the energy—volume coefficients at a given temperature and, moreover, diminishes the temperature variation of the energy—volume coefficients at constant volume. In other words, addition of salt to the water produces the same qualitative effects as raising its temperature.

At or near room temperature, the apparent volumes of salts dissolved in water increase with temperature; the apparent thermal expansibilities are positive and, moreover, decrease as the concentration of the solution rises. In this respect the behavior of salts dissolved in water differs from that of salts dissolved in any other solvent. All these anomalies disappear at higher temperatures, the apparent volumes of the salts passing through maxima around 50° C as the temperature is raised at constant pressure.

One feature of these investigations deserves emphasis, namely, the valuable information

given by an analysis of the effect of temperature at constant volume. As one more example, we may note that the apparent volumes of sodium chloride and sodium bromide in water continue to increase when the temperature is raised at constant volume, the maxima noticed on the constant-pressure curves having disappeared. When the total volume is kept constant, the presumption is strong that the long-range forces between the ions of the salt and the water molecules are also constant. The increase in apparent volume with temperature under such conditions brings out clearly its dependence on the molecular distribution in the liquid (water), in striking contrast with the behavior of salts in glycol under similar circumstances. Furthermore, a comparison of the apparent-volume—temperature curves at constant total volume for sodium chloride and sodium bromide furnished conclusive evidence that the main difference between these two salts dissolved in water lay in the relative attractions of the chloride and bromide ions for water molecules, and not in their effects on the molecular distribution.

Another interesting feature of the results is that they indicate that at temperatures between 180 and 200° C the thermodynamic properties of water solutions certainly become much simpler than at room temperature. All this work points to a continuously increasing similarity between salt solutions in water and in glycol (the model solution) as the temperature rises. This fact encourages us to believe that fairly simple theoretical considerations may give results of useful accuracy for dilute aqueous solutions at higher temperatures. The importance of a knowledge of the behavior of dilute aqueous solutions at these temperatures and at high pressures in the study of ore-depositing solutions, or of volcanological phenomena, makes it desirable to extend the pressure—volume—temperature studies into this region at an early date.

SOLUBILITY OF CALCIUM SULFATE IN SEA WATER

Measurements of the relative solubilities of gypsum and anhydrite in aqueous solutions of sea salts at 30° C are now completed

[Posnjak], and the results have been published. With increasing concentration of sea salts the solubilities of gypsum and of anhydrite at first increase rapidly, then pass through maxima, and finally decrease gradually. This decrease is more rapid for anhydrite, and at 4.8 times the normal salinity of sea water anhydrite becomes the stable phase. Sea water is unsaturated with respect to

gypsum and anhydrite, and the foregoing results show that on evaporation most of the calcium sulfate in sea water will be deposited as gypsum. It is probable, therefore, that sedimentary deposits of anhydrite were laid down at temperatures above the transition point of these minerals or were formed from gypsum after it had been deposited from marine solutions.

RADIOACTIVE ELEMENTS IN ROCKS AND IN SEDIMENTS FROM THE OCEAN FLOOR

It is now well established that a knowledge of the relative amounts of various radioactive elements in different rocks and of the total amount and distribution of radioactive elements in the Earth's crust is of prime importance in a study of the ages of rocks and minerals and in the problem of the thermal history of the Earth. Though much attention has been given to the securing of the necessary data, it must be emphasized that our information in this field is far from complete. It has been shown that radioactive elements are distributed throughout all the materials of the Earth's crust, the largest concentration being found in granites and the least in sedimentary rocks, but little systematic work has been done. In particular, the vast areas of the Earth that lie under the ocean have hardly been studied at all, and such results as have been obtained are of doubtful significance. With the core-sampling gun developed by Piggot it is possible, not only to extend by several hundred per cent the area from which samples may be taken, but to obtain from any place on the ocean floor a core several feet long in which the vertical and horizontal distribution of radioactive elements in the ocean-bottom sediments may be studied.

Determinations of radium in cores from the bottom of the Atlantic and Pacific oceans formed the main part of this year's work [Piggot, Urry]. Four cores from low latitudes were examined, three from the Bartlett Trough (between Cuba and Jamaica) and a red-clay core taken by the Scripps Institution of Oceanography at a point 220 miles west-southwest of San Diego, California. The

radium content was determined at nine or more points in each core. At the surface the amount of radium in each core is larger than the average found in igneous rocks, a result which agrees with previous fragmentary data. The radium content increases with depth for some distance until it passes through a maximum, and thereafter decreases steadily. The same general type of distribution was found in all four cores. It should be mentioned that the initial increase of radium content with depth is very rapid and that consequently the observed radium content of specimens obtained with the older "snapper sampler" depends to a large extent on the accidental depth to which the snapper penetrated the sediment. In the introductory paragraphs reference has already been made to the implications of this newly found radium distribution in depth.

Cores taken from the foot of the slope on the continental shelf off the Grand Banks, at a position approximately midway between the Grand Banks and the Mid-Atlantic Ridge, were also examined, the radium content being determined at ten or more places in the core. The radium-content curves obtained for these cores have the same general shapes as those just described, but a somewhat erratic distribution of radium in the cold-water zones of these cores has been noted.

As a result of these measurements it now seems certain that radioactive equilibrium is not attained in any of the cores or in sea water itself. Accordingly, information of great interest about the age and rate of deposition of the sediments is to be expected

if the amounts of the individual elements uranium, radium, and ionium can be measured. To accomplish this, an alpha-particle counter has been built and calibrated in terms of the Laboratory's standard radium solution. It has been established that uranium, radium, and ionium may be separated from each other by a simple chemical procedure involving co-precipitation, and that the alpha-particle counter may be used to determine the amount of each element. A determination of uranium and ionium in a Finnish granite—a rock of adequate age for the existence of the equi-

librium relation between uranium or ionium and the previously measured radium—indicates that the method is satisfactory.

The newly built apparatus by which the radium content of rocks and core samples is determined in a semiautomatic and routine way was used in all the work on the core samples, after being checked by samples whose radium content had been determined by other methods. In addition, the radium contents of twenty-two samples of rocks received from the National Bureau of Standards were measured with the new apparatus.

PHYSICAL PROPERTIES OF ROCKS AND MINERALS

DETERMINATION OF CRYSTAL STRUCTURES BY X-RAY DIFFRACTION

The study of the structures of the gold-silver-telluride minerals sylvanite, krennerite, and calaverite has been continued during the past year and is now nearing completion. Because of the unusual nature of the structures that were proposed as a result of studies of the relative intensities of the scattered rays, it was considered desirable to apply the most powerful methods available to confirm them. Four Patterson and Fourier series were computed, and although the work was laborious, up to 200,000 terms being computed in a single series, it was greatly facilitated by the use of an improved set of strips and stencils together with a sorting board. The segregation of the odd and even terms with the new stencils reduces the labor to less than half that formerly required. A new and excellent equator Weissenberg photograph of sylvanite was made, the cause of the unsatisfactory nature of previous ones having been detected and eliminated. The results of these calculations confirm the structures and the values of the parameters previously proposed. Contour maps of the electron density distribution in the unit cells as projected on various planes have been prepared from the results of the Fourier analysis [Tunell].

HEAT OF MELTING OF ALBITE

In order to control the speculations made about the alteration of rocks by igneous and

other activity, to place on a quantitative basis generalizations about the thermal processes in the Earth, and to provide the data necessary for thermodynamic calculations, it is essential that data on the heats of melting and of transformation of minerals and on their specific heats be obtained with as high precision as possible. An apparatus satisfactory for this purpose has been built and tested [Roberts]. The determination of the heat of melting of the important mineral albite presents some difficulties. It is nearly impossible to obtain adequate amounts of completely crystalline pure synthetic albite or to estimate with sufficient precision the fraction of crystalline solid in a partially crystallized sample. On the other hand, the natural product, although well crystallized, is known to contain troublesome impurities. Direct measurements gave an average of 77 calories per gram for the heat of melting of two samples of natural albite containing 2 per cent anorthite and 1 per cent orthoclase. Many years ago Bowen calculated the heat of melting of albite from the melting curves in the system albite—anorthite and gave the value 48.5 calories per gram. Some of the assumptions involved in the calculation may be open to question, but the divergence of the two results is difficult to explain. Another method of attack, however, presented itself. Studies of the system sodium oxide—alumina—silica in the Laboratory have shown that albite and sodium disilicate form a simple binary system with

a eutectic at 765° C and that mixtures in this system crystallize very readily and completely even when they contain as much as 80 per cent albite. This observation offered an adequate source of crystalline albite mixed with a known amount of additional material, and on the assumption that the heat of mixing of liquid albite with liquid sodium disilicate is negligibly small, the latent heat of melting of albite was computed from the observed heat of melting (at 780°) of an albite-disilicate mixture (50 weight per cent of each) and the known heat of melting of sodium disilicate. This result was 40 calories per gram for the heat of melting of albite. The discrepancy among these three figures illustrates the difficulty of determining latent heats of substances like silicates, and indicates that further study on other mixtures containing albite is necessary.

MAGNETIC AND X-RAY DIFFRACTION STUDIES OF SULFIDE MINERALS

An investigation is under way on the solid solution series of sulfur in ferrous sulfide [Posnjak], a series which includes the mineral pyrrhotite. These solutions comprise a small field which extends to not much over 4 per cent of extra sulfur. Only those materials in the sulfur-rich half of the series are ferromagnetic. In spite of numerous investigations of these solid solutions, some of which are very recent, many statements regarding the character of the phases appearing in the series and their behavior are in need of verification. The thermal study carried out in this Laboratory a few years ago did not clarify all aspects of the problem. Accordingly, further attempts to solve it were made by means of magnetic measurements. The

results obtained to date indicate quite clearly that the Curie temperature of the ferromagnetic members of the series rises appreciably with an increasing sulfur content. However, the absence of ferromagnetism in the part of the series with the lower sulfur content cannot be ascribed to a lowering of the Curie temperature below room temperature, but appears to depend on some fundamental change in properties with composition. X-ray examinations indicate that three different phases may be distinguished in the series of solid solutions between room temperature and 350° C. The differences in the diffraction patterns of these phases are small, however, and require much further study. A very considerable difficulty in the study of these solid solutions lies in the sluggishness with which transitions of phases take place.

DETERMINATION OF VOLATILE MATERIALS IN ROCKS AND MINERALS

Although the exploratory phase of this work is now completed, the subject is by no means exhausted, and indeed the significance of the nature and exact amounts of volatile materials in rocks and in sublimes or incrustations from volcanic regions is just being realized. Volatile materials play an important role in the propagation of heat and chemical reactions throughout rocks, and the traces they leave behind give important data for inferences. In order to facilitate the routine and precise analysis of gases in rocks, an apparatus embodying the latest improvements in vacuum technique and design is being constructed [Shepherd]. This apparatus is simpler than the older one formerly used in the Laboratory, but is more powerful and versatile.

EXPLORATORY AND COOPERATIVE STUDIES

GEOPHYSICAL AND GEOLOGICAL EXPLORATIONS IN THE VOLCANIC REGIONS OF GUATEMALA

The investigations of present-day igneous activity, in which the Department of Terrestrial Magnetism is cooperating with the Laboratory, were continued during the past

year by another expedition to Guatemala [Zies, Wright, Rooney, Green, Adams]. In the plan of this work two primary objectives have been set up: (1) the focusing of all the resources of newly developed instruments and technique on the exploration of atmospheric,

surface, and subterranean phenomena in and around this region where so many forms of volcanic activity are concentrated; and (2) close observation of the physical and chemical aspects of volcanic activity in the field, with a view to devising significant laboratory experiments which may provide the basis for an understanding of the natural phenomena and may supply a clue for disentangling their many complexities. Needless to say, the conclusions of such laboratory studies should be continuously rechecked in the field. It must, of course, be emphasized that both these objectives can be attained only after explorations have been made and the problem of reaching the areas of most interest has been solved—a problem whose simplicity is more apparent than real.

Gravity measurements. The Pacific slopes and the highlands of Guatemala are covered, often to a great depth, with pumiceous deposits of a very low density. Although the absence of topographic maps and precise geological information concerning this area makes interpretation difficult, it seemed desirable to make a few tests of the use of gravity determinations—*a priori* a very promising method—for estimating the thickness of the layers of pumice and for appraising the applicability of this method to general problems of volcanism. Two Brown gravity pendulum instruments and accessory equipment, kindly loaned by the U. S. Coast and Geodetic Survey, were taken on the expedition, and stations were occupied at the National Observatory in Guatemala City and near the Western Observatory (Observatorio del Occidente) in Quezaltenango [Wright]. The auxiliary electrical circuits in the instruments gave trouble from mutual interference and from interference with a near-by radio transmitter, but these difficulties were overcome, satisfactory measurements were secured, and some valuable experience in the operation of these instruments under exacting service conditions was obtained.

Measurements of earth resistivity. The character of the pumiceous deposits in the plain around the city of Quezaltenango indicates a relatively recent origin, and suggests

that the pumice originated from local sources. To determine the depth of this material, measurements of the electrical resistance of the ground mass were made at a number of stations arranged in a grid [Rooney, Green]. The results show that there is no pronounced change for a depth of more than 1000 feet in the central portion of the mass. Earth-resistance measurements on the plain around Guatemala City indicate that the pumice is probably of different origin from that around Quezaltenango.

Magnetic observations. The survey of 1939 showed that measurements of the vertical intensity of the Earth's magnetic field gave valuable information about the depth or extent of masses of hot igneous material underlying the volcano Santa María. Similar hot masses are believed to underlie the plain of Quezaltenango, and for this reason magnetic measurements at points in this vicinity were carried out [Green]. In addition, a number of the former stations were reoccupied. The analysis of these results has not yet been completed.

Atmospheric ionization. An apparatus for counting separately the α and β radiation in the atmosphere was provided by the Department of Terrestrial Magnetism. After preliminary trials at low altitudes, it was set up at the main camp at an elevation of 7000 feet near the crater floor of the volcano Santa María. Later, a trail was cut through the vegetation on one of the ridges of the southern flank of the volcano, at an elevation of 10,000 feet. This vantage point is swept by the prevailing winds carrying steam and other gases from the active dome, Santiaguito, which is on the edge of the old crater. A comparison of atmospheric ionization in this region and in one not exposed to volcanic emanation was attempted, but the excessive humidity soon rendered the apparatus inoperative. Our experience has enabled us to suggest changes in the design of the electrometer which will render it useful under the rigorous working conditions in the vicinity of active volcanoes.

Seismic observations. Two portable seismometers were mounted on posts buried 3 feet in the ground and records were ob-

tained at the main camp on Santa María and on the crater floor. The instruments, however, responded only to comparatively strong shocks and were unaffected by the heavy rock slides from the shattered wall of Santa María. It was concluded that more sensitive seismographs will have to be employed if a record of the disturbances produced by the rather quiet extrusions of lava in this region is desired.

Microphones. In his well-known work at Mont Pelée in Martinique, F. A. Perret has used buried microphones to pick up audible frequencies transmitted through the ground during volcanic activity, and he has been able to follow the intensity of the activity by noting the character of the sound in the phones. Mr. Perret lent us duplicates of his apparatus, and supplied explicit instructions for its use. The apparatus was set up at a number of stations close to the base of the active dome, Santiaguito. Rock slides on Santa María, some 800 feet away, were audible in the microphones, but otherwise nothing but instrument noises was detectable. This lack of response of the microphones in this locality, where according to other evidence volcanic activity is intense, indicates that it is desirable at some opportune time to try out an instrument with higher sensitivity in certain frequency ranges.

Geological and geochemical results. From the camp site at an elevation of 10,000 feet on Santa María the complex alternation of layers of lava and clastic material that make up Santa María may be studied very conveniently. Indeed, the processes leading to such formations are now visible. Constant and heavy erosion of the vertical walls is gradually filling the crater with fragmental material. If in the near or far distant future this is engulfed in another great extrusion of lava, a volcanic breccia of the type already in place will be formed.

The fumaroles on the lower eastern slope of Santiaguito appeared to have altered little during the year that had elapsed since the previous visit. Access was gained for the first time, and with much difficulty, to a

group of fumaroles 400 feet higher up the slope and in line with the lower group. These are on a more consolidated part of the dome where the slope has a gradient amounting to from 35 to 37°. In contrast with the complete absence of sulfur in and around the lower group of fumaroles, abundant quantities of this element were found around the upper group; indeed, the sulfur seems to act as a cement binding the soil particles together, thus forming a crust that renders the ground impervious to steam. When the crust was broken, steam escaped and molten sulfur was observed 2 inches below the surface. The steam escaping from the fumaroles has a temperature of from 120 to 350° C, and transports much hydrogen sulfide and sulfur. Many samples of incrustations and gases were collected for laboratory study.

In the report for last year attention was called to the intermittent extrusions of hot lava that came from the upper part of the western slope of Santiaguito. This year it was possible to approach close enough to measure the temperature of the lava with an optical pyrometer—a difficult operation, as only a short time elapses between the appearance of the glowing lava and its disintegration and fall down the steep slopes. Its temperature was found to be 725° C. Relying on experience gained last year, the expedition was able to reach the foot of the western slope of Santiaguito and establish a camp about a quarter of a mile from the nearest point of extrusion of the lava. Careful observations were made of the process of extrusion. It is not explosive; the hot mass merely swells out quietly and then breaks up and rolls down the slope. A mass roughly 9 meters in circumference was seen to disintegrate and fall near one of the observation points, where its temperature, determined immediately with a thermoelectric thermometer, was found to be 690° C. The mode of extrusion and an examination of the cooled exudations lead to the conclusion that relatively fresh lava coming from within the dome engulfs and reheats the surrounding rock, and that when the resulting mass, whose temperature is now

quite low (700° C), comes out on a 33° slope it does not flow, but breaks up into fragments and rolls away.

SURFACE FEATURES OF THE MOON

The activities of the Committee on Study of the Surface Features of the Moon have been continued. This is a cooperative project between Mount Wilson Observatory and the Geophysical Laboratory, begun some years ago in the effort to bring to bear on this problem the combined experience and facilities within the Carnegie Institution. A large amount of observational material has been gathered by the committee and a portion of it is now being assembled for publication. The report on the results of visual measurements of the polarization of light from selected parts of the moon's surface and from various samples of terrestrial substances is in course of preparation [Wright]. Measurements of polarization by use of a photoelectric cell and of a quartz polarization spectrograph are in progress.

The measurements of slope angles of various surface features of the moon, as made on the series of 500 lunar photographs taken during July 1938 at Mount Wilson Observatory, are being continued. This is a time-consuming task, but data are being gathered for a rough topographic map, with contour intervals of 200 meters, of the central part of the moon, out to 45° from the center of the lunar disk visible from the Earth. A photographic map of the moon is also in preparation. For this purpose photographs of the moon taken at the Newtonian focus of the

100-inch telescope are transformed by a special photographic method, so that in each transformed negative the moon's image is projected on the plane of mean libration and in the same perspective projection and scale.

MEASUREMENTS OF GRAVITY WITH NEW PORTABLE INSTRUMENT

Work on the new model of the gravity meter has been continued, and the instrument is now being given a thorough field test in the vicinity of Washington. In contrast with previous models, the temperature of the torsion spring is maintained constant by an electrical thermostat; the instrument is so designed, however, that ice can be used for temperature control, if necessary. It has not yet been possible with the electrical thermostat to hold the temperature constant to better than several tenths of one degree centigrade; but for many measurements this degree of constancy appears to be adequate, especially as the spring is held at rest and is not under strain except for the 4 to 6 minutes required to make a measurement at a given station. The special features of the new model are proving on test to be satisfactory, and they enable the observer to reduce the time needed to occupy a station to about one-half that required with the preceding instrument. As soon as the field tests have been completed, the instrument will be used for a series of gravity measurements along selected lines in critical regions in which information is desired regarding the distribution of gravity anomalies and the degree of isostatic adjustment.

HIGH-PRESSURE INVESTIGATIONS

EXTENSION OF EXPERIMENTAL RANGE OF HYDROSTATIC PRESSURE

In connection with various problems in Earth science, both the Geophysical Laboratory and the Department of Terrestrial Magnetism have been concerned with the properties of matter at the high pressures that are known to exist within the depths of the Earth—pressures far beyond the present ex-

perimental range. It appears that there has been no satisfactory theoretical basis for extrapolating physical properties to these extreme pressures or for pushing to the limit the capabilities of high-pressure apparatus. By the joint efforts of members from the two departments, a careful analysis was made of the present status of pressure work with a view to canvassing the possibilities of a large

increase in the experimental range of observations under high pressures. There seems little probability of finding new varieties of metal that would permit a really worth-while enlargement of the pressure range, but, fortunately, a promising line of attack is afforded by the remarkable increase of compressive strength of materials when they are subjected to superimposed hydrostatic pressure.

An apparatus consisting of one small pressure generator enclosed inside another was designed and constructed in such a way that a hydrostatic pressure of approximately 18,000 atm. could be developed in the outer vessel and then held constant while a carboloy piston was forced into the inner cylinder, thereby generating the high pressure. Test experiments indicated that pressures of the order of 200,000 atm. could be generated in the inner vessel [Goranson, Johnson], and also showed that the outer confining pressure increased the compressive strength of the specimen of carboloy used as the piston to more than three times its value at atmospheric pressure. It is probable that the effect on the ultimate strength of the walls of the inner bomb is of even greater magnitude. The advantage of this two-stage "cascade" apparatus, therefore, lies not only in the circumstance that the second stage immediately doubles the pressure range, but also in the great increase of strength caused by the confining pressure on the inner bomb. The preliminary experiments have shown the desirability of certain alterations in order to obtain better precision and control. These modifications are now being incorporated, and investigations on auxiliary devices, such as thrust gauges, are being continued.

The theory on which the construction of this apparatus is based has been developed in the past year [Goranson]. In this theoretical treatment the total energy of a solid is divided up in the usual way into a potential energy and a kinetic energy, and the variability of these quantities with respect to temperature, hydrostatic pressure, unidirectional stress, and

a combination of hydrostatic pressure and unidirectional stress is examined. Two types of failure are considered: brittle rupture, which occurs when the potential energy increases above a certain value; and plastic flow, which is treated as a two-phase phenomenon depending on the thermodynamic potential of the system, involving both the kinetic and potential energies. Various predictions of the theory as to the effect of external pressure on the strength of materials have been verified and have proved useful in correlating phenomena connected with the deformation and flow of rocks.

FERROMAGNETIC CHANGES UNDER PRESSURE

Because of the interest in the question as to the existence of ferromagnetic substances under the conditions prevailing in the interior of the Earth—a question that bears directly on the origin of the Earth's magnetic field—the work on the effect of high pressures on the Curie points of certain minerals has been continued [Goranson, Johnson, Posnjak]. The older pressure apparatus was modified so as to increase the temperature range, and a very sensitive reactance bridge was constructed for measuring the toroid coils, whose inductance is of the order of 30 microhenrys. This bridge will detect changes of about 5 parts per million. With this apparatus the permeability of the material forming the core of the toroid is determined at different temperatures and pressures, and the temperature of the Curie point, that is, the inversion from the ferromagnetic to a nonferromagnetic form, is thus found for any pressure. The spinel consisting of CdFe_2O_4 and MgFe_2O_4 has been examined and it has been found that the Curie temperature of this substance is raised 3°C by 6000 atm. pressure.

With a view to extending the investigations of the effect of pressure on the Curie temperatures to as wide a variety of substances as possible, plans are being made for measurements on purified gadolinium (Curie point around 16°C).

SUMMARY OF PUBLISHED WORK

- (1013) The radium content of an ocean-bottom core. C. S. Piggot and W. D. Urry. *Jour. Wash. Acad. Sci.*, vol. 29, pp. 405-410 (1939).

Determinations of the radium content of the surface material of the ocean bottom secured by the ship *Carnegie*, previously made by Piggot (*Amer. Jour. Sci.*, vol. 25, pp. 229-238, 1933), revealed a surprisingly high concentration of this element as compared with that in the igneous rocks from which it must have come.

In an effort to throw some light on the nature of this radium concentration in ocean-bottom sediments, an apparatus was previously developed to secure vertical cores extending some 10 feet below the surface of the sediment. Such cores, from the North Atlantic between Newfoundland and Ireland, proved to be very complex, but the one here reported is of recent "blue mud" throughout and fairly uniform in radium content. This fact reflects both the uniformity of the material and its relatively recent deposition. Attention is called to the circumstance that the presence or absence of uranium per se could have no effect on the radium content of this core, and to the conclusion that the radium content is controlled very largely, especially at depths corresponding to a few thousand years, by the deposition of ionium. Why the sea should be deficient in radium, in relation to uranium, and the sediments have more than the equilibrium amount will probably be explained by further studies of such cores as are here described.

- (1014) Phase equilibrium relations in the system $\text{Na}_2\text{SiO}_3-\text{Li}_2\text{SiO}_3-\text{SiO}_2$. F. C. Kracek. *Jour. Amer. Chem. Soc.*, vol. 61, pp. 2863-2877 (1939).

The phase equilibrium relations in the system $\text{Na}_2\text{SiO}_3-\text{Li}_2\text{SiO}_3-\text{SiO}_2$ are described in this paper. The work was carried out by the method of quenching supplemented by thermal analysis.

There is one ternary compound, NaLiSiO_3 , which is an end member of the solid solution series $(\text{Na}_2,\text{NaLi})\text{SiO}_3$. It melts incongruently, at 847°C . At the liquidus in the system, the primary phases are $(\text{Na}_2,\text{NaLi})\text{SiO}_3$ solid solutions, Li_2SiO_3 , $\text{Na}_2\text{Si}_2\text{O}_5$, and $\text{Li}_2\text{Si}_2\text{O}_5$, all three of which form solid solutions of limited extent, and the three modifications of SiO_2 , namely, quartz, tridymite, and cristobalite. The liquidus fields meet at two ternary eutectics: one at

697° C , with $(\text{Na}_2,\text{NaLi})\text{SiO}_3$, Li_2SiO_3 , and $\text{Na}_2\text{Si}_2\text{O}_5$, the other at 637° C , with $\text{Li}_2\text{Si}_2\text{O}_5$, $\text{Na}_2\text{Si}_2\text{O}_5$, and quartz as the eutectic constituents. $\text{Li}_2\text{Si}_2\text{O}_5$ melts incongruently throughout its region of existence in the system, the reaction temperature descending from 1033° C in the binary system $\text{Li}_2\text{SiO}_3-\text{SiO}_2$ to 641° C , the peritectic end point in the ternary system, with $\text{Li}_2\text{Si}_2\text{O}_5$, Li_2SiO_3 , $\text{Na}_2\text{Si}_2\text{O}_5$, and liquid in co-existence.

The inversion temperature of quartz and tridymite has been redetermined. The temperature of $870 \pm 10^\circ \text{ C}$, given by Fenner in 1913, is confirmed, the value now obtained being $867 \pm 3^\circ \text{ C}$.

Refractive indices of glasses of various compositions in the system were measured.

A discussion of solid-solution relationships of sodium and lithium compounds in general is given, with particular reference to the theoretical aspects of the subject.

Minor revisions of the phase relations in the systems $\text{Na}_2\text{SiO}_3-\text{SiO}_2$ and $\text{Li}_2\text{SiO}_3-\text{SiO}_2$, particularly with respect to the polymorphic behavior of $\text{Na}_2\text{Si}_2\text{O}_5$ and $\text{Li}_2\text{Si}_2\text{O}_5$, are presented.

- (1015) Pressure—volume—temperature relations in solutions. III: Some thermodynamic properties of mixtures of aniline and nitrobenzene. R. E. Gibson and O. H. Loeffler. *Jour. Amer. Chem. Soc.*, vol. 61, pp. 2877-2884 (1939).

The thermodynamic properties of mixtures of aniline and nitrobenzene have a twofold interest, first because they present an example of a series of solutions made from components which differ only slightly in their net internal pressures as given by the Tait equation, and secondly because the absorption of light by the solutions responds in an unexpected way to changes in their thermodynamic environment. The specific volumes at 25° C , the thermal expansions at 10° intervals between 25 and 85° , and the compressions to various pressures up to 1000 bars at 25 , 45 , 65 , and 85° of six solutions of aniline in nitrobenzene covering the whole range of concentration were measured. These data were represented by suitable equations from which the volumes, the thermal expansibilities, and the compressibilities could be computed at any pressure and temperature within the range of the observations. From these results it was possible to compute the pressure—temperature co-

efficients, the energy—volume coefficients, and the volume changes on mixing, and also to examine the variation of these quantities when the temperature was changed at constant volume. In the light of the results of this analysis, a correlation was suggested between the effect of temperature and of mixing on the molecular distribution in the liquids on the one hand and the internal pressures and volume changes on mixing on the other. The attractive internal pressures of the solutions varied with volume in the same way as those of the pure components and could be calculated from constants for the pure components and the composition of the solution expressed in terms of a generalized fraction which really introduces an empirical constant in a way that has hitherto not been exploited. Attempts to express the volume changes on mixing by the well-known "Regular Solution" type of equation modified by the introduction of the generalized fraction were made with moderate success.

- (1016) Identification of diamond in the Canyon Diablo iron. C. J. Ksanda and E. P. Henderson. Amer. Mineralogist, vol. 24, pp. 677-680 (1939).

Small black and transparent grains embedded in a slice from a Canyon Diablo iron have been identified as diamonds by means of the X-ray powder spectrum method and by microscopic examination. The diamonds occur associated with some graphitic material within a troilite area lining the inner wall of a cavity.

The previous identification of diamond in a stony meteorite is mentioned.

- (1017) Note on the fluorine content of rocks and ocean-bottom samples. E. S. Shepherd. Amer. Jour. Sci., vol. 238, pp. 117-128 (1940).

There has been little information about the amounts of fluorine present in rocks, the lack of data being due to the unreliable analytical methods available. The Willard and Winter procedure furnishes an easy and surprisingly accurate method for fluorine determination. This report shows that instead of being a very minor constituent of rocks, fluorine is present in about the same amount as chlorine and must be considered in rock analyses. A tentative average value of about 0.04 per cent is suggested, and some indications point to regional concentrations. Ocean-bottom samples contain about the same quantities as the rock. In both rocks and

ocean-bottom samples the fluorine varies with the nature of the material.

- (1018) Notes on fluorine. E. S. Shepherd. Bull. volcanologique. (In press; publication delayed because of international conditions.)

A brief treatment of the subject matter of paper no. 1017, presented at the meeting of the International Volcanological Association held in Washington, D. C., in September 1939.

- (1019) Fabric criteria for distinguishing pseudo ripple marks from ripple marks. Earl Ingerson. Bull. Geol. Soc. Amer., vol. 51, pp. 557-570 (1940).

Statistical grain-orientation studies of two unmetamorphosed ripple-marked sandstones, a ripple-marked quartzite, and four pseudo ripple marks show that a distinction between ripple marks and pseudo ripple marks can be made from fabric characteristics even when field data are equivocal. Some of these pseudo ripple marks had been previously interpreted as ripple marks.

Quartz diagrams were prepared for all the rocks, and mica diagrams for those that contained mica. Without exception, the axes of the pseudo ripple marks are important fabric directions, both for mica and for quartz. In one case the axis of the pseudo ripple mark is parallel to the *a* fabric direction (direction of motion during deformation), and in two others it is parallel to the *B* fabric direction (axis of folding). In the fourth example of a pseudo ripple mark the nature of the control is not apparent. The ripple-mark axes are also principal fabric directions for mica, but there are important and easily recognizable differences between the arrangement in the ripple marks and that in pseudo ripple marks, the mica being distributed uniformly and symmetrically in the pseudo ripple marks studied, but in the actual ripple marks being confined to the troughs and lower parts of the back slopes, and thus being asymmetric with respect to the *s*-plane. Quartz orientation in the ripple-marked sandstones may or may not be significant, but it is radically different from that found in the pseudo ripple marks. In the metamorphic pseudo ripple marks, the quartz axes form girdles; in the actual ripple marks, if there is preferred orientation of the quartz, the *c*-axes tend to lie in the bedding plane, more or less parallel to the axis of the ripple mark.

- (1020) Physics of stressed solids. Roy W. Goranson. *Jour. Chem. Phys.*, vol. 8, pp. 323-334 (1940).

The internal energy of a system is subdivided into a work or potential function and a thermal or kinetic function, the former expressed in terms of the current electrostatic theory of intercrystalline bonding, and these functions then examined for variations of temperature, hydrostatic pressure, unidirectional stress, and combined hydrostatic and unidirectional pressure. From these considerations a theory is evolved which not only seems satisfactorily to explain and correlate phenomena of deformation, creep or plastic flow, cold working, elastic after-working, rupture, shear, and certain other phenomena hitherto described as "anomalous" effects, but also has been corroborated experimentally in some of its predictions, in particular for the effect of hydrostatic pressure on deformation and compressive strength. The mechanism evolved consists of two processes, one of which is an elastic deformation which is a function of the strain or potential energy of the system. Failure occurs here by "brittle" rupture, wherein the maximum extension or maximum internal tension is the criterion. The other is a deformation by means of a two-phase transfer mechanism and is a function of the thermodynamic potential relations of the system. This latter type is also a function of time and therefore a function of the rate of application of load. When both processes of this mechanism are operative, failure occurs by shear; the criterion for this type of failure is given by a function of time, the strain or potential energy, and the thermodynamic potential relations of the system. Expressions are derived for creep or plastic flow of polycrystalline substances from the thermodynamic potential relations which not only satisfy the well-known phenomena of creep in metals but also express recent empirical creep data of some substances immersed in liquids in which they are somewhat soluble. An expression is also derived for the "brittle" potential type of rupture under combined thrust and hydrostatic pressure.

- (1021) Geysir in Iceland. Tom. F. W. Barth. *Amer. Jour. Sci.*, vol. 238, pp. 381-407 (1940).

Observations on the geology of Geysir, its behavior, discharge, and temperature distribution, have led to the conclusion that the structure of the Geysir system and the mechanism

of its action are more complicated than was thought by Bunsen.

In an appendix special consideration is given to Thorkelsson's assumption that a reduction in pressure caused by spring gases and steam as they rise in narrow channels is the real factor in geyser action. A bibliography of Geysir and geyser action is also appended.

- (1022) Experimental flow of rocks under conditions favoring recrystallization. David Griggs. *Bull. Geol. Soc. Amer.*, vol. 51, pp. 1001-1022 (1940).

"Flow" in stressed solids: an interpretation. Roy W. Goranson. *Ibid.*, pp. 1023-1033 (1940).

These two papers have been combined because of their complementary nature. The first one, by Griggs, presents experimentally observed creep or flow phenomena in rocks when subjected to certain different physical conditions of confining pressure, confining media, and stress. The second one, by Goranson, presents an interpretation of "flow" for these conditions. According to the hypothesis presented here, plastic flow in solids takes place by means of a change-of-phase transfer mechanism, as solid to fluid to solid or solid to solution followed by recrystallization of the solid. The relations derived constitute part of the author's more general treatment of stressed solids. From these considerations it is seen that the quantity labeled "viscosity" for solids is related to the "activation energy." If the hydrostatic confining pressure is sufficiently high, then release of the energy of deformation stored up in the crystal lattice can take place only by this change-of-phase mechanism.

- (1023) Equilibrium between vapor and liquid phases in the system $\text{CO}_2-\text{H}_2\text{O}-\text{K}_2\text{O}-\text{SiO}_2$. George W. Morey and Michael Fleischer. *Bull. Geol. Soc. Amer.*, vol. 51, pp. 1035-1057 (1940).

Chemical reactions that take place by the agency of hot aqueous solutions and hot compressed gases, known as hydrothermal and pneumatolytic processes, respectively, are of primary importance in the formation of many ore deposits. Concerning the mechanism of these processes, and especially concerning the mechanism of transport of material and both the relative and absolute importance of transport in liquid and vapor phases, there is no unanimity of opinion.

Field studies of ore deposits have shown that many ore-bearing solutions contain more than one volatile constituent, and numerous questions have been raised thereby that cannot be answered satisfactorily at present because pertinent physicochemical data on such systems are lacking. Accurate prediction of the behavior of such solutions can be made only after obtaining a comprehensive knowledge not only of the solid—liquid equilibria (the solubility relations) but also of the effects of temperature and pressure on the distribution of volatiles between the liquid and vapor phases in multicomponent systems. The system here reported is the first attempt to obtain the latter type of data experimentally.

The solutions concerned in ore deposition are extremely complex in composition, probably containing more or less of all the common rock-forming elements as well as a number of volatile constituents. It is not feasible at present to undertake the experimental study of such complex solutions. The number of components had to be reduced, to simplify the problem to a point where it could be handled. Accordingly, this work was restricted to the four-component system $\text{CO}_2\text{—H}_2\text{O}\text{—K}_2\text{O}\text{—SiO}_2$. Water and carbon dioxide are two of the most important volatile constituents of magmas. Furthermore, the other possible choices, such as the halogen or sulfur compounds, would have greatly increased the experimental difficulties due to corrosion. K_2O and SiO_2 were chosen as the other components because the high solubility of the potassium silicates in water allows working at relatively low pressures and because the relations in the bounding ternary system were known from the earlier work of Morey and Fennar.

The study of the distribution of two volatiles between a liquid phase and a vapor phase requires the determination of the total amount and composition of each phase after equilibrium has been reached, or, what is equivalent and experimentally simpler, determination of the total amount and composition of one of the phases and knowledge of the amount and composition of the original mixture. Since it is experimentally impracticable to sample the liquid phase, it is necessary to use some method for separating the phases and subsequently analyzing one or both. The method finally adopted consists in separating the phases by means of a valve and then analyzing the vapor phase.

The apparatus consists essentially of two bombs whose inner chambers are connected through an opening within a valve block. One of these,

of small free volume, contains all the liquid phase plus a small known proportion of the vapor phase; the other, the greater part of the vapor phase.

By the use of this apparatus, a study has been made of the equilibrium between vapor and liquid in the system $\text{CO}_2\text{—H}_2\text{O}\text{—K}_2\text{O}\text{—SiO}_2$ at 500° C. Partial pressures of H_2O ranged up to 400 atm., of CO_2 , up to 25 atm., and the mixtures used had ratios of $\text{K}_2\text{O}:\text{SiO}_2$ from 1:1 to 1:4.

The distribution ratios of the fraction of CO_2 in the vapor to the ratio of the percentages of CO_2 to H_2O in the liquid are indicative of the tendency of the metasilicate melts to retain CO_2 and of the tendency toward expulsion of CO_2 with more siliceous mixtures. With drop in pressure at constant temperature and ratio $\text{K}_2\text{O}:\text{SiO}_2$, the composition of the vapor changes toward higher contents of CO_2 . An incidental study was made of the rate of solution of quartz in potassium carbonate solutions.

- (1024) The effects of pressure, temperature and chemical composition on the absorption of light by mixtures of aromatic amines and nitro compounds. R. E. Gibson and O. H. Loeffler. *Jour. Amer. Chem. Soc.*, vol. 62, pp. 1324–1334 (1940).

This paper gives the results of an investigation of a new phenomenon which was observed incidentally in our regular work on the thermodynamic properties of solutions under pressure. It was found that the absorption of visible light by solutions of aromatic amines in nitro or nitroso compounds (aniline dissolved in nitrobenzene being a typical example) is pushed very significantly toward the longer wave lengths when the hydrostatic pressure over the solutions is raised at constant temperature, and also when the temperature is raised at constant volume. When the temperature of the solutions is raised at constant pressure the absorption of visible light may increase, decrease, or remain constant; in any case the change is small, and it is noteworthy that the solutions which absorb light most strongly at room temperature have the largest negative temperature coefficients. These results have been correlated into a consistent theory which uses only ideas that are applicable to pure liquids, and which avoids any specific assumption as to the formation of colored compounds by the hypothesis that the colors of the solutions arise from the mutual polarizations of molecules when appropriate groups are in

close proximity, account being taken of the influence of pressure and temperature on the collision frequency, the distance of closest approach, and the effect of short-range attractions between groups. In this correlation the data given in Laboratory paper no. 1015 (see abstract) were used.

It has also been shown from orienting experiments that substituents in the nitro compound and in the amine influence the absorption of light by the solutions in a way that parallels closely their effects on the reducibility of the NO_2 or NO group on the one hand, and the electron mobility in the amino compound on the other. It is suggested that the polarizations which give rise to the colors of the solutions may be regarded as primary steps in possible reactions, such as oxidation and reduction, involving transfer of electrons from the aromatic amine or hydrocarbon to the oxygen of the nitro or nitroso groups.

- (1025) Deposition of calcium sulfate from sea water. E. Posnjak. Amer. Jour. Sci., vol. 238, pp. 559-568 (1940).

Stability relations of gypsum and anhydrite in solutions of sea salts are of considerable geological interest, as many deposits of these minerals are generally considered to be of marine origin. Since it has been shown that the transition point, gypsum—anhydrite, is not governed by a dissociation pressure relation, but by a four-phase equilibrium, only relative solubilities establish their stability either alone or in presence of other salts. The present determinations in solutions of sea salts were made at 30° C . The solubility of gypsum as well as that of anhydrite first increases rapidly in the presence of increasing amounts of sea salts, then goes through a maximum at about twice the usual salinity of sea water, and then gradually decreases. However, the decrease is more rapid for anhydrite, and an intersection of the two curves takes place at approximately 4.8 times the usual salinity, the point at which anhydrite becomes the stable phase.

Sea water is unsaturated with respect to calcium sulfate, and only after its salt content has increased by evaporation to 3.35 times the usual salinity can deposition take place. Between this concentration and the one required for stable deposition of anhydrite, nearly one-half the total amount of calcium sulfate present in sea water will be deposited at 30° in the form

of gypsum. Since at a somewhat lower temperature, at which evaporation of a marine basin may be assumed to have taken place, the conditions in all probability will not be greatly modified, a large portion of calcium sulfate may always be expected to be deposited as gypsum. Sedimentary marine deposits of pure anhydrite must therefore either be at least partly derived from originally deposited gypsum, or have been formed close to or above 42° , the transition point of the two minerals.

- (1026) Fracture and flow in stressed solids. Roy W. Goranson. Trans. Amer. Geophys. Union, 21st annual meeting, pp. 698-700 (1940).

A stressed solid may deform permanently by rupture, which is an elastic breakdown, or by plastic flow, which involves a change-of-phase mechanism. Generally these two effects are combined. The relation of the latter mechanism to metamorphic processes and to deep-focus earthquakes is discussed. The inadvisability of applying the term viscosity to plastic-flow phenomena is also pointed out and substitution of a more general term suggested.

- (1027) Review and discussion of article by L. C. Graton, "Nature of the ore-forming fluid," Econ. Geol., vol. 35, pp. 197-358. Earl Ingerson and George W. Morey. Ibid., pp. 772-785 (1940).

Graton's paper is discussed, parts of it in detail, under the following heads:

1. *State of solutions.* It is agreed that orthomagmatic solutions (i.e., the magma itself) are probably never above their critical temperature. However, magmatic emanations in equilibrium with the magma are almost certainly gaseous near the magma, but may condense to liquid where the temperature is low enough. The transport of nonvolatile material by gaseous solution is shown to occur in important amounts, and semiquantitative data are given. The impossibility of evaluating the relative importance of liquid and gaseous solutions from field evidence is pointed out.

2. *Mechanism of separation.* If ore-forming fluid is separated as a different phase from the magma, both field and laboratory evidence are more nearly in accord with separation as a gaseous phase than with separation as an immiscible liquid.

3. *Timing.* The separation of a different phase

is thought of as a continuous process. The separated phase can have important effects early in the cycle, but probably becomes more important as an ore-forming fluid late in the cycle.

4. Motive power. Gas pressure is considered to provide at least part of the propelling force. Collapse of the roof would tend to pump compressed gaseous as well as liquid solutions upward.

5. Deposition: (a) *State.* Three cases are mentioned, and the impossibility of telling from field evidence whether the solutions were liquid or gaseous is pointed out. (b) *Alkalinity.* The character of the solutions with respect to alkalinity or acidity is a problem that must be worked out for each individual deposit.

- (1028) Physical effects of extreme pressures. Roy W. Goranson. *Scientific Monthly*, vol. 51, pp. 524-535 (1940).

The first part of the paper presents, with some illustrative examples, a generalized picture of the kinds of change expected at higher hydrostatic pressures. The relation of some recent developments in theoretical physics to certain ultra-high-pressure phenomena is also indicated. In the discussion of practical utilizations it is shown why certain compromises must be made with theoretical expectations and why metastable systems are able to exist for long periods of time. The design of high-pressure assemblages is treated in the second part of the paper, not only for its own sake but also because it illustrates the important field of non-uniform pressure phenomena. In fact, it was only through a recent theoretical development in this field that the feasibility of extending the previous experimental pressure range very materially was made evident. An example of the application of this hypothesis is given by a two-stage cascaded pressure device.

- (1029) Dehydration of pollucite. Michael Fleischer and C. J. Ksanda. *Amer. Mineralogist*, vol. 25, pp. 666-672 (1940).

Samples of pollucite from two localities have been studied under the microscope and by means of X-rays before and after dehydration. This study is further evidence that the water present in the mineral is not an essential part of the crystal lattice. The shape of the dehydration curve is not, in this case at least, a reliable means of deciding the role of water in a mineral.

- (1030) Annual Report for the year 1939-1940.

- (1031) Potentiometers for thermoelectric measurements. W. P. White. Symposium on "Temperature: its measurements and control in science and industry" (Amer. Inst. Physics), pp. 265-278. New York, Reinhold Pub. Corp. (1940). Leakage control by shielding. W. P. White. *Ibid*, pp. 279-283 (1940).

POTENIOMETERS FOR THERMOELECTRIC MEASUREMENTS

In 1905 the beginnings of a wide use of thermels led to a demand for potentiometers capable of measuring to 0.1 microvolt, or even somewhat better. The chief obstacle was intrusive electromotive forces, the worst of which came from the switches. By 1908, means, seven in all, had been devised for overcoming this obstacle. The method was not to redesign the switches, but to arrange them so that their intrusives did not get into the galvanometer circuit. This greatly eased the burden on the most important device of all, the eliminating switch, which removes the error from all thermal intrusives. A parallel development was two devices for rapid reading, the provision for reading two figures on the galvanometer, and, in reading several thermels along together, a selector switch for the dials which worked together with the one for different thermels.

Twenty or thirty years later, potentiometers are being improved so that the intrusives in them are nearly or quite as small as 0.001 microvolt. This improvement is at present of no particular advantage except as it is used to enable Wenner's very rapid eliminating switch to be employed. This switch may often give several times the precision of the older methods, but its advantage is confined to the measurement of constant voltages, and observations with it are slower than by the older rapid methods.

LEAKAGE CONTROL BY SHIELDING

An equipotential leakage shield, consisting of metal plates suitably connected together, intervening between a galvanometer system and its environment, will absorb leakage currents from outside, shunting them completely away from the system, and thus enabling comparatively inferior insulation to give better results than almost the best can do without the shield. Such a shield is best extended into electric furnaces into which thermels are inserted. Methods less effective, but often easier and therefore sometimes preferable, are also discussed.

- (1032) Temperatures of volcanoes, fumaroles, and hot springs. E. G. Zies. Symposium on "Temperature: its measurements and control in science and industry" (Amer. Inst. Physics), pp. 372-380. New York, Reinhold Pub. Corp. (1940).

The obvious emission of heat associated with volcanic activity and with the related fumarole and hot-spring manifestations has provoked much speculation as to its origin. It has also been responsible for an enormous amount of laboratory investigation of the temperature range within which the mineral species that make up igneous rocks have been formed. The determination of the temperatures that prevail during these periods of thermal activity has therefore received the attention of many investigators.

In this paper the various temperature-measuring devices used in these investigations at specific areas are described and the results obtained are presented. The limitations of the methods and the difficulties encountered when they are applied in the field are given in detail.

The results show that temperatures as high as 645° C were found in the steam vents of the extensive fumarolic area of the Valley of Ten Thousand Smokes. They also show that the

temperature of lavas ranges from the 725° characteristic of the sluggishly moving andesitic lava of Santiaguito, in Guatemala, to the 1150° characteristic of the rapidly moving basaltic lava of Nyamagira, in Africa.

The determination of temperatures, together with the study of the chemical environment of these thermal areas, has suggested many additional problems for investigation in the laboratory, especially the role played by vapor-phase activity in transporting various constituents of the igneous materials toward the surface.

- (1033) Automatic control of laboratory furnaces by the Wheatstone bridge method. Howard S. Roberts. Symposium on "Temperature: its measurements and control in science and industry" (Amer. Inst. Physics), pp. 604-610. New York, Reinhold Pub. Corp. (1940).

Regulators of this type are in constant use in the Geophysical Laboratory for control of high temperatures. The paper includes a general discussion of the Wheatstone bridge type of controller and its applicability. It brings up to date material presented in Laboratory publication no. 573 (see report for 1925-1926, pp. 69-70).

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DEPARTMENT OF TERRESTRIAL MAGNETISM

Washington, District of Columbia

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SUMMARY

The activities of the Department in earlier years had to be directed chiefly toward obtaining field- and observatory-data, but during this report-year (July 1, 1939 to June 30, 1940) continued reduction and intensive study of results previously obtained and development of attack by experiments in the laboratory have constituted the major portion of the Department's work. Improved delineation of fact and extension of theory have emerged from these investigations. An important factor in such delineation and extension, particularly in terrestrial magnetism and electricity, is the interchange of ideas and the coordination of effort facilitated by international scientific gatherings. Three such congresses were held in the United States during the report-year. These were the Sixth Pacific Science Congress, in San Francisco; and the Seventh (triennial) Assembly of the International Union of Geodesy and Geophysics and its seven Associations, and the Eighth American Scientific Congress, in Washington. In all these, papers, discussions, and resolutions pertaining to geomagnetism and its associated fields were outstanding features. The staff of this Department participated actively in the first and last, and took a leading part in preparing and conducting the second.

Research in geomagnetism as a world-wide geophysical phenomenon requires close international collaboration, since many geomagnetic and geoelectric phenomena cannot be successfully studied unless they are observed all over the globe. The importance of a geophysical congress therefore lies partly in the exchange of ideas and in the personal contact of scientists whose institutions happen to be in different countries, but mainly in obtaining agreement on the kind of observations needed

in each country to stimulate world-wide cooperative projects and to organize and standardize the work and the dissemination of results.

Geomagnetic investigations. The disruption caused by the war threatened to stop the procuring of much indispensable information, for instance, the scheme of magnetic characterization indicating for every day the degree of disturbance. The international magnetic character-figure, ranging from 0.0 to 2.0, is an average of qualitative estimates rather vaguely defined, made at about fifty observatories all over the world; its standard of measurement changes when a number of reporting stations drop out. Mainly through the initiative of members of this Department, a new scheme for a quantitative measure of magnetic activity has been introduced by the International Association, namely, the magnetic 3-hour-range index K between 0 and 9. Through joint studies with the U. S. Coast and Geodetic Survey, the K -index was established as a valuable abstract of the magnetograms, providing even single observatories with good estimates of world-wide magnetic conditions. This index is now currently derived from data obtained by seven American-operated observatories, and is published weekly by *Science Service*. It gives, for the first time, a detailed homogeneous series for the intensity of solar corpuscular radiation affecting the Earth, useful both in its terrestrial aspect—as in scientific or commercial radio work—and for its bearing on solar physics. Violent magnetic storms with $K=9$ occur only a few times near a sunspot-maximum, but it is equally rare that any full 3-hour interval is perfectly free from disturbance. This means that the Earth is almost constantly, even near sunspot-minimum,

under the influence of (presumably solar) particles, weak as this influence may be at times.

The intensity of the ionizing solar wave-radiation absorbed in the ionosphere on the daylight hemisphere can likewise be measured geomagnetically in the amplitudes of the solar daily magnetic variation. The records of horizontal intensity at the Huancayo Magnetic Observatory, in which the magnitude of the solar daily magnetic variation is exceptional, were analyzed for the whole available series, 1922–1939, and a measure for the ionizing solar wave-radiation was abstracted and compared with the relative sun-spot-numbers, as the only available complete series of daily measures of solar activity. The correlation-coefficient between them is +0.92 for monthly means, +0.97 for quarterly means, and +0.984 for annual means. These are the closest established relations so far found between phenomena on the Sun and Earth. The geomagnetic measure for the ionizing solar wave-radiation is being improved by combining data from several observatories in order to arrive at daily values.

In connection with this work on data from Huancayo, the Moon's influence on the horizontal force was next isolated and studied. Certain additional features of that influence were also found, all of which can be interpreted by the dynamo-theory as the magnetic field of electric currents induced in the oscillating ionosphere by the Earth's permanent magnetic field. These currents must flow low in the ionosphere, where recombination of ions is rapid, because the lunar variation is found to be confined to the daytime; neither primary ionospheric currents nor secondary currents induced within the Earth's body cross the night hemisphere near the equator. The ionospheric air-motions appear to be much more dominated by tidal oscillations than are the winds near the ground, because the Moon's geomagnetic effect is plainly expressed in the magnetograms even for single days. The partial tides connected with the Moon's varying distance from the Earth are clearly recognized in the geomagnetic records, but the relations of the ampli-

tudes and phase-angles of the geomagnetic partial tides to the main semidiurnal tide differ significantly from those in the gravitational tidal forces. The study of geomagnetic tides provides thus a new approach to the study of resonance-phenomena in atmospheric oscillations.

A better understanding of the Earth's general magnetic field and of its secular variation was obtained through a representation of the field by a series of properly disposed elementary magnets. From this new representation, inferences may be drawn regarding the depth at which the magnetic field originates and the quantitative relation between the general field and its secular variation. The general magnetic field may be effectively resolved into a symmetric field and a residual field. The inferences drawn from the representation are that the residual field originates at no greater depth than the surface of the Earth's inner core, which seismological evidence indicates is in a fluid state, and that secular change is a continual modification of this residual field—a modification so extensive that in the course of a few centuries its entire structure is completely changed. No inferences may be drawn regarding the depth at which the symmetric field originates or whether it also is affected by secular change. It is clear that secular change does not affect this symmetric field to so great an extent proportionally as it does the residual field.

Studies of magnetic storms suggest that the atmospheric current-system responsible for the daily variation of disturbance arises in part from electromotive forces generated mainly along the auroral zone.

A general theory of analysis of surface magnetic fields was developed. This method permits analysis of fields (such as those of magnetic storms) for which the method of spherical harmonic analysis is impracticable. It is based on Green's theorem and permits the separation of an observed surface magnetic field into its parts of external and internal origin. An application to the field of magnetic storms, hitherto not analyzed for high latitudes of the Earth, shows that about 60 per cent of the observed field is of external

origin; departures from this value are greatest near the auroral zone. The method also affords a convenient means of estimating the errors introduced, in effecting approximate analysis, by assuming parts of the Earth's surface to be plane. An extension of the theory permitting estimates of the space-distribution of electric currents responsible for the field is being attempted with a view toward its utility in geomagnetism and geophysical prospecting.

The magnetic storm of March 24, 1940, probably the greatest magnetic storm ever recorded, was an event of unusual geophysical interest. Disturbances of radio communication during great magnetic storms because of concomitant effects on the ionosphere, and disruption of wire-communication through electric currents induced in the Earth, have frequently been noted, but during this storm the induced earth-currents attained such magnitude that electric power-systems were severely affected—the first time such effects have ever been reported. Computations were made of the intensity of currents which could be produced by magnetic changes, and for extreme cases it was found to be sufficient to produce the observed effects on power-lines. Thus, an increased practical importance of research in terrestrial magnetism has been shown, for the lengthy observations extending over a century supply definite information on the probability of occurrence of such storms and therefore on the extent to which it is advisable to revise electrical installations to avert their effects. To study these great magnetic storms more thoroughly and to supply complete and accurate records, a wide-range magnetic recorder has been installed in the Standardizing Magnetic Observatory of the Department at Washington, capable of recording greater variations than have ever been observed.

The continued study of the magnetic declination in past geological ages through measurements on a more extensive collection of varves from the Hartford series shows that the deduced declinations in the varves collected at East Windsor Hill are in approximately the same direction as those at East Hartford. Further publications on this prob-

lem will not be attempted, however, until a more adequate series has been collected.

The attainment, in March 1940, of hydrostatic pressures in excess of 200,000 atmospheres at the Geophysical Laboratory made possible further measurements on the shift of the Curie temperature. For a cadmium-magnesium-iron spinel and with pressures to 10,000 atmospheres, a shift of the order of $0^{\circ}002$ C per bar was found. The extension of these results to some of the deep-lying constituents of the Earth's crust promises to have an important bearing on a theory of the Earth's permanent magnetic field.

The anomalies in magnetic vertical intensity measured last year in the vicinity of the volcano Santa María in Guatemala were compiled. Since these data were insufficient in number to afford a satisfactory geological interpretation, they were supplemented by nearly 750 additional observations early in 1940; analysis of these data is under way.

Terrestrial electricity. A critical discussion on ionic equilibrium—the ion-population problem—in the atmosphere indicates sources of possible error. The equations for ionic equilibrium show that the fraction of the nuclei of condensation in the atmosphere, which are electrically neutral, is related to the geometrical mean of two ratios corresponding to two pairs of parameters in the equations. The value of the fraction previously found at Washington is greater than any of those reported for other places and is about 50 per cent greater than the average. This was confirmed by a more extensive series of observations made by another observer using different equipment and exercising particular precautions to avoid sources of error. Another equally important and quite unexpected result is that this fraction (0.75) is the same for air in all conditions, in a closed room or outside, in the city or in the open country, and at night or in daytime.

The analysis of the diurnal variation in the vertical electric conduction-current in the atmosphere at College, Alaska, indicated a local component which is not caused by heretofore considered factors operating in the atmosphere adjacent to the Earth. That com-

ponent, therefore, is thought to have broader geophysical interest than many local atmospheric-electric phenomena, some of which were subjects of investigation.

From harmonic analyses of the data for the 11 years from 1924 to 1934 at the Watheroo Magnetic Observatory for potential-gradient, positive and negative conductivities, air-earth current, ratio of positive to negative conductivity, and difference between positive and negative conductivity, the 24-hour wave was found to predominate in all cases. For potential-gradient, agreement was good with the universal 24-hour wave found over the oceans from observations made aboard the *Carnegie*, except for the wet months May to August. The analyses show a lag of about 90 minutes for the 24-hour wave of the negative conductivity as compared with that of the positive conductivity. The 24-hour wave in the air-earth current shows considerable seasonal range, the maximum occurring at about 19^h GMT in December and January, and at 23^h in July and August. The average magnitude of the air-earth current was about 10×10^{-7} esu, being about that found over the ocean aboard the *Carnegie*.

Ionization as measured with a thin-walled chamber in a closed room is less when large ions are numerous than when they are few. Tests indicate that the diminution in ionization cannot be explained on the earlier proposed hypothesis that large ions falling out of the air carry radioactive material with them and consequently tend to clear the air of ionizing material. The phenomenon thus remains unexplained and invites additional experimental work.

Experiments on large ions from gas flames indicate that the recombination-coefficient is not a constant, but diminishes from about 15×10^{-9} initially to about 0.6×10^{-9} in about 90 minutes after the ions are formed. This diminution is explained as arising from a gradual increase in the average size, through recombination, of the large ions.

Tests show that molecular ions are produced in abundance by the action of ultraviolet light from a mercury-arc lamp. Numerous large ions are also found in air irradiated

with the ultraviolet light. Preliminary tests have indicated that uncharged particles are produced by ultraviolet light and combine with the molecular ions and so produce large ions, the result being that the number of molecular ions present is greatly diminished. Assuming this mechanism, the rate of production of molecular ions was deduced and was found sufficient to account quantitatively for the increase in ionization required for the production of radio fade-out during a chromospheric eruption.

Cooperation in the volcanological investigations of the Geophysical Laboratory consisted of two projects: (a) the design and construction of a portable "ionization-meter" which will provide information about the variation with position of the amount of radioactive matter in the air and of that in the Earth near the surface; (b) surveys (December 1939 to February 1940) of the electrical resistivity of earth, particularly as a function of depth, at two sites in the highland volcanic region of Guatemala: one 11 km from the volcano Santa María, the other near Guatemala City. Preliminary analyses of the results obtained in these surveys show a very uniform structure and indicate that the beds of volcanic ash are of very great depth.

Ionosphere. The accumulation of homogeneous ionospheric data from the Watheroo and Huancayo magnetic observatories has made detailed analysis of associated ionospheric and geomagnetic effects possible. The automatic equipment for observation of the ionosphere has been in operation for more than two years. Systematic changes in the ionosphere associated with geomagnetic activity have been found; these are not the same at different latitudes. Even small fluctuations in geomagnetism are accompanied by associated changes in ion-density in the ionosphere at both observatories. Introduction of the new 3-hour-range index, K , of geomagnetic activity facilitates the investigation of systematic changes. This investigation is the first step in separation of individual factors which are involved in the complicated changes in the outer atmosphere.

The great magnetic storm of March 24,

1940 was associated with ionospheric changes of almost unique character. Coincidently with the beginning of the geomagnetic changes, the F_2 -layer was carried upward and disappeared. An unusual feature of this disturbance at Huancayo, where it occurred near midday, was the formation of a new F_2 -layer in place of the old. Because the original ion-density of the region was reduced to a low value, it may be regarded as an un-ionized atmospheric region which is suddenly exposed to uniform solar radiation. This offers an unusual opportunity to determine the rapidity with which new ionization is produced and existing ionization is destroyed.

The important but troublesome problem of reducing measured virtual heights of ionospheric regions to their actual heights was greatly simplified by development of graphic methods. The older methods were impracticable of application to more than a very few records; the new method permits mass-reduction of observations to actual heights, so that the general knowledge of the ionosphere has been greatly extended.

Studies of the E -region of the atmosphere are being pursued vigorously, since it appears that within this region much of the solar influence is translated into geomagnetic effect. At present this investigation is assuming the following forms: (1) comparison of continuous observations of E -region ion-density at different locations with existing theories, and (2) investigation of special conditions during solar eclipses. Eclipse-observations were made during the solar eclipse of April 7, 1940; during the early stages of the eclipse, maximum ion-density decreased more rapidly from normal-day conditions than was predicted, which would indicate that the Sun is not giving out the ultraviolet ionizing radiation uniformly from all parts of its surface. Plans have been perfected and arrangements made for similar observations at the Huancayo Magnetic Observatory during the solar eclipse of October 1, 1940. Experiments have been devised for precise measurements of height-variation of the E -layer.

Rayleigh scattering from atmospheric gases in the path of an intense, modulated search-

light-beam was measured to heights of 40 km; a 24-inch transmitting mirror and carbon arc were used as light-source, and a 30-inch mirror, with a photoelectric cell, and an amplifier were used in the receiver. Above a limit of haze, which varies from 4 to 10 km, the scattering agrees with that calculated for the usual atmosphere. This work showed that with a 60-inch mirror-system the height may be extended to 70 to 90 km. For this measurement, and also to determine the distribution of ozone below 20 km, a program using 60-inch mirrors was begun in June 1940.

Analysis of the world-wide cosmic-ray effects at the Cheltenham, Christchurch, Godalming, Huancayo, and Teoloyucan observatories was continued and excellent agreement was found between these effects at Huancayo and Teoloyucan and between those at Cheltenham and Christchurch. There is a significant difference in the general trend in cosmic-ray intensity between that at Huancayo and Teoloyucan and that at Cheltenham and Christchurch, which may indicate an important change in the latitude-effect with time. (Further details regarding cosmic-ray researches are given in the report of the Institution's Committee on Coordination of Cosmic-Ray Investigations, pages 113-132.)

Nuclear physics. The program of studies on the interactions of the primary particles of matter—protons, neutrons, and electrons—all of which have magnetic properties, was advanced by several experiments. Measurements were made on the scattering of slow and fast neutrons by collisions with hydrogen nuclei (protons), on the resonance-scattering of protons by helium nuclei, and on the splitting of the heavy-hydrogen nucleus into a proton and a neutron by high-energy gamma radiation. An important part of the work on this type of fundamental analysis of the simplest things in Nature was the effort to improve technique, looking toward similar studies of interactions of particles at still higher voltages, corresponding to still more intimate collisions. The large electrostatic generator of the Atomic-Physics Observatory, built two years ago to extend these studies, then represented a necessary extrapolation of

technical knowledge, and much research and development have been needed to attain the expected limits of this equipment. This development is not complete, but definite progress has been made.

Rapid progress was made in the plans to expand activities in nuclear physics to include cooperative projects which make use of artificially radioactive tracers for studies of chemical and biological processes (see Year Book No. 38). These plans center around a large cyclotron, which is to be a duplicate in all essentials of the 60-inch cyclotron at the University of California. The building, which includes laboratory-facilities for physics, chemistry, and biology, was about 70 per cent complete in June, and the large parts of the cyclotron itself were designed and ordered. Assembly of the complete instrument is scheduled for the autumn and winter. Several investigations relating to photosynthesis, physiology of the embryo, genetics, and chemotherapeutic action, using tracers and nuclear radiations, were made during the year, in cooperation with other laboratories of the Institution, the National Cancer Institute, and the Johns Hopkins University.

Observatory-work. The observatories at Huancayo in Peru and at Watheroo in Western Australia continued their extensive programs of geophysical observations. Co-operative work was continued in atmospheric electricity at Apia, in atmospheric electricity and earth-currents at Tucson, and in maintenance of international magnetic standards at the Cheltenham Magnetic Observatory of the U. S. Coast and Geodetic Survey.

Miscellaneous. The report-year saw the distribution, in August 1939, of *Terrestrial magnetism and electricity* (volume 8 of the series on "Physics of the Earth" sponsored by the National Research Council), eight of the fourteen contributors to which are members of the Department's staff; and the completion in June 1940 of the comprehensive two-volume work *Geomagnetism*, by Research Associates S. Chapman and J. Bartels. These two treatises mark an epoch in the science of terrestrial magnetism and electricity.

There were no retirements during the report-year. C. R. Duvall, who retired January 31, 1937, after some twenty-four years of long and fruitful service as expert computer, died February 3, 1940.

INVESTIGATIONAL AND EXPERIMENTAL WORK

TERRESTRIAL MAGNETISM

Those of the staff engaged in geomagnetic investigations were Berkner, Fleming, Forbush, Johnson, Johnston, Ledit, McNish, Toreson, and Vestine. Research Associates Bartels and Chapman took important part both through constructive advice and through investigations at Berlin and London; both were delegates at the Washington Assembly of the International Union of Geodesy and Geophysics, and the former was in residence at Washington from August 18, 1939 to September 23, 1940.

PERMANENT FIELD

Physical representation of the geomagnetic field. A new method of representing the geomagnetic field was developed (McNish).

The geomagnetic field can be represented to a first approximation by a dipole of moment 8.1×10^{25} CGS units appropriately placed near the center of the Earth, as has long been recognized. However, this single dipole represents only about 80 per cent of the observed field. It was found that the remainder of the field, the "residual field," can be represented to within the accuracy of the observations by 14 radially directed dipoles midway between the center and the surface of the Earth. This depth, which is identical with that at which seismological evidence indicates a discontinuity of the elastic properties of the Earth, was not arbitrarily chosen; placement of the hypothetical dipoles at a greater or lesser depth would have required a much

greater number for the same closeness of representation. This is regarded as evidence that the residual field has its origin between the inner core of the Earth and the surface. On the other hand, the quantity of magnetic matter necessary to produce the residual field is so great that it cannot be confined to the outer subsurface layers of the Earth's crust. This first establishment of some definite basis for estimating the depth at which the Earth's field originates is of fundamental importance in the development of any theory of the origin of that field.

A similar representation of the field of magnetic secular variation was also developed, the dipoles being located at the same depth. However, a further restriction could be imposed in this case, namely, that the dipoles be all of the same intensity. The two systems of dipoles, those for the residual field and those for the secular-variation field, tend to be "orthogonal," that is, the secular-variation dipoles are close to the zero isodynamic lines of the residual field. The average strength of the dipoles of the residual field is $1/80$ of that of the centrally located dipole, while the dipoles of the secular-variation field are about $1/100$ as strong as those of the residual field. Accordingly, if secular variation were to proceed at its present rate for 100 years or so, a new residual field would be built up differing markedly from that which exists at present. In this connection, all historic records of secular change suggest that it does not continue in the same direction and sense at any one place for more than a century or so, and this generalization is supported by measurements of the residual magnetization of geological sediments (see earlier annual reports).

The concept strongly emphasized by this study is that the residual field, which accounts for about 20 per cent of the magnetic field observed at the surface, and its changes originate largely or entirely at a lesser depth than that of the Earth's fluid core. Secular change consists almost entirely of the changes in this residual field, the form of which is completely altered from century to century.

In an investigation of the potential of the Earth's magnetic secular variation (Vestine)

it was estimated that if secular change be attributed to changes in magnetization near the Earth's surface, there must be superposed upon the Earth's field yearly the field due to a thickness of 700 meters of radially magnetized material of unit magnetic moment in the region of active secular change just west of Africa. Such large changes in magnetization in the Earth's crust appear exceedingly improbable, as has been pointed out by others, so that attempted explanations of secular change on this basis are unsatisfactory.

A paper on magnetic secular variation in the Pacific area (Vestine) presented at the Sixth Pacific Science Congress discussed, with special reference to the Pacific area, the isoporic charts and equivalent magnetic shell for secular change (mentioned in the last annual report). The part of the secular-variation field observed near the boundary of the Pacific Basin may assist in interpreting changes in structural features of the Basin. The probable linear dimensions of these areas of localized secular change are probably smaller than for those of a more world-wide character, thus permitting their separation if sufficiently detailed surveys should become available. Magnetic profiles of the field taken across the boundary of the Basin would probably assist in marking out the limits of the boundary where this is uncertain (as in the South Pacific), and in conjunction with gravity-measurements should give useful information respecting geological structure. The depth at which secular change originates is not likely to be greater than the horizontal width of the "vortices" appearing in the equivalent magnetic shell for secular change drawn for the Earth's surface. A part of secular change, likely to be larger where the crustal motions are larger, must of necessity originate in the Earth's crust.

The technique of spherical harmonic analysis developed by Gauss in 1842 and later improved by Neumann, Schmidt, and Schuster has long furnished one of the most useful tools in the study of geomagnetism. Since the time of Gauss little attention has been devoted by geophysicists to the development of other techniques of field-analysis, although a num-

ber of new developments in potential-theory have appeared during the past century in researches on hydrodynamics, heat, and sound, where boundary-problems analogous to those of geomagnetism sometimes appear. Since the Gaussian method of spherical harmonics proves inadequate in certain field-problems, an investigation has been undertaken of possible alternative methods offering greater scope in general application (Vestine).

The Gaussian method is usually convenient and useful in the case of fairly simple geomagnetic fields, but may become cumbersome and impracticable when the field-distribution over the Earth is complicated. In a field of this type a large number of spherical harmonic terms are usually required in obtaining a sufficiently close approximation to the field. In the case of magnetic storms a large number of harmonics of high degree are required, and hence other techniques seem indicated. The same is true in general of other geomagnetic fields, but in these the complicated features are relatively unimportant and can usually be neglected. In fact, since the complicated field-structures are frequently inadequately measured, their inclusion may contribute to inaccuracies in analysis. The Gaussian method may even prove impracticable in the case of very simple fields if these are of types expressible only by many important spherical harmonic terms. The fundamental limitation of the method is one of representation, a difficulty which can be overcome by the use of surface-integrals in field-analysis.

The Gaussian method permits the separation of an observed field over the Earth into its component parts of external and internal origin. A beginning has been made in the development of a more fundamental method. A general theorem, applicable to any regular closed surface S , gives the difference between the magnetic potentials of external and internal origin in the form

$$(V_e - V_i) = (1/2\pi) \int_S [Z/r - V\delta(1/r)/\delta n] dS$$

where Z and V are the total vertical force and potential on S , respectively, n is the outward normal, and r is the distance from the point on the closed surface S at which $(V_e - V_i)$

is required, to the element of area dS . Since the potential $V = (V_i + V_e)$ is known (or can be derived apart from a constant taken to be zero in geomagnetic applications using observed horizontal components of force), a separation of V into parts of external and internal origin is effected. This integral simplifies in the case of a sphere. An analogous expression is used in the separation for vertical force. Various surface-distributions of magnetic matter giving rise to the observed field have been obtained. The known solutions for the problems of Dirichlet and Neumann permit the continuation of the surface-values of the field into adjacent harmonic regions. The separation of the observed field into external and internal parts by means of surface-integrals is especially useful in the treatment of problems in which it is desirable to use data in the form of graphs, instead of in analytical form. A practical general method of computing possible external or internal current-distributions capable of reproducing the observed field has not yet been found, although solutions have been obtained using the alternating process of Schwartz. The possibility of using machine procedures in field-analysis is also being considered.

Geomagnetism and volcanic structure. Reduction of the results from the first magnetic survey of the volcano Santa María in Guatemala was virtually completed. No alterations were made in the preliminary conclusions drawn from early reduction of a limited quantity of the data. In accordance with expectations, the magnetic field in the region of the volcano is extremely complex and requires many more data for interpretation than have been obtained.

A detailed topographic map of the portion of the region covered by the magnetic survey was made, utilizing the auxiliary data obtained, and was supplied for the expedition of 1939–1940. On the basis of past experience, detailed plans were made for the magnetic program of this expedition, and instrumental equipment was prepared and calibrated. The magnetic profiles across the volcanic rift made at a number of places in 1940 by Green support in general the observations previously

made near Santa María; compilation of these data is not yet in form for detailed study and analysis.

Effects of great pressure. The development at the Geophysical Laboratory of a cascade high-pressure bomb was successful and the new pressure-range of 200,000 bars was realized. This apparatus makes it possible for the first time to investigate the magnetic properties of the Earth's interior at pressures comparable to those which actually exist. At the same time, the technique of measuring Curie temperature was developed by Goranson of the Geophysical Laboratory and by Johnson of the Department, and measurements were made on a cadmium-magnesium-iron spinel (supplied by Posnjak of the Geophysical Laboratory) in the low-pressure region up to 10,000 atmospheres. A shift of the order of 5°C for a change of pressure of 10,000 atmospheres was indicated. This large shift is supposed to be associated with the low Curie temperature of this spinel and is the first directly measured shift of this magnitude. The measurements required the development of an alternating-current bridge to measure changes in inductance of 10^{-10} henry. It is believed that a modification of this method can be used at the superpressures just developed. This work, of course, is of great importance to theories involving the Earth's permanent magnetic field.

COSMIC RELATIONS

Geomagnetic studies on fluctuations in solar radiation (Bartels). The theory of geomagnetic time-variations and aurora, supplemented by direct studies of the ionosphere by means of wireless waves, leads to the well known working hypotheses that the Sun, in addition to rays penetrating to the ground, sends us radiation to be classified as wave-radiation, W , and particles, P . W ionizes the day side of the ionosphere and is geomagnetically effective in the solar and lunar daily variations, S and L , while P reaches also the Earth's night side, mainly in polar regions, and produces auroral and magnetic disturbances with their associated effects. The intensities of both W and P vary in parallel

with the 11-year sunspot-cycle (expressed in the relative sunspot-numbers R), but with the difference that P lags behind R , while W shows no lag.

The fluctuations of both W and P are of fundamental interest for geophysics as well as for solar physics. Progress at the Department during the report-year is summarized below:

As to solar corpuscular radiation P , various schemes for measuring it by its effect, the "magnetic activity," are in operation, especially the "characterization"—international magnetic character-figure C for days, and American character-figure C_A for half-days—and the monthly u -measure expressing the variability of the equatorial "ring-current." Quantitative measures of activity for smaller time-units had always seemed desirable, but no adequate proposal had been made for a successful separation of the magnetic variations due to P and to W until the practical and theoretical interest in ionospheric conditions led, mainly on the initiative of this Department, to action by the International Association of Terrestrial Magnetism and Electricity at its meeting in September 1939, at Washington, D. C. The Potsdam geomagnetic index, introduced in 1938, was taken as a model for the new magnetic 3-hour-range index K . The new scheme was developed by Bartels and H. F. Johnston in collaboration with Captain N. H. Heck, Chief of the Division of Terrestrial Magnetism and Seismology of the U. S. Coast and Geodetic Survey.

Each collaborating observatory assigns to each 3-hour interval, beginning at $00^{\text{h}}, 03^{\text{h}}, \dots, 21^{\text{h}}$ GMT, one of the integers 0 to 9 as range-index K , by regarding the magnetic variations as superpositions of K -variations (effects of P to be measured) and of non- K -variations (effects of W such as regular daily variations, or after-effects of P , to be eliminated). For each observatory, a permanent scale is adopted once for all, giving the limits within which the 3-hour ranges of the K -variations, measured in units of force γ ($1\gamma = 0.00001$ CGS unit), define the index K . In practice the 3-hour range for each mag-

netic element is defined as the difference between the highest and lowest deviation, within the 3-hour interval, from a smooth and regular daily variation to be expected for that element on a magnetically quiet day, according to the season, the sunspot-cycle, and, in some cases, the phase of the Moon. This range is considered for each of three rectangular field-components (X , Y , Z , or D , H , Z); only the largest of the three ranges determines K .

The assimilation of frequency-curves guided the choice of scales for K . The ideal is to define them so that, in a sufficiently long time, for instance in the year 1938, each station assigns the same aggregate number of indices $K=0$, $K=1$, etc.

The correlation between the indices assigned for various observatories is high. Some stations exhibit a systematic daily variation of K ; at Sitka (Alaska), for instance, the three intervals between local midnight and 09^h are more disturbed. Such regional features are faithfully indicated by K ; for the purpose of measuring the intensity of the solar corpuscular radiation P , however, it is desirable to eliminate this daily variation. This is done by a second assimilation of frequency-curves which provides keys for transforming each index K into a reduced index K_r . For each observatory twenty-four such keys are established, namely, for the usual three four-month seasonal groups, and for the eight intervals of the Greenwich day. In combining these reduced indices K_r in a world-wide index K_w as a measure of P , half weight is given to tropical observatories, where P can be less distinctly recognized than in polar regions.

For longer intervals, such as days and months, other measures are derived from the indices K and K_w , namely, the daily index B and the monthly average 3-hour amplitude A .

Extensive tables of K , B , and A have been published, for the months January to June 1938, and have been used for a thorough discussion of the statistical and physical aspects of the new measures. At the end of the report-year tables for the years 1938 and 1939, based on data from seven American-operated ob-

servatories and from Potsdam, Germany, were ready for publication. Weekly tables for K and K_w are prepared on the basis of telegraphic reports from the five magnetic observatories of the U. S. Coast and Geodetic Survey and the Department's two observatories, Watheroo and Huancayo, and published by *Science Service*. Their usefulness is increasingly recognized, in particular for radio work, both scientific and commercial.

Twenty-seven-day recurrences are better recognized in K than in the daily character-figures. In this connection, Bartels proposed a hypothetical division of magnetic storms into two types: In sweeping across the Earth's orbit, the front of a freshly formed stream of solar particles may either hit the Earth ("nascent stream type") or not; in the latter case the rotating arm of the stream may eventually overtake the Earth from the evening side ("mature stream type"). These possibilities must be considered when it is attempted to infer the travel-time of solar particles from the Sun to the Earth, from the time-interval between a solar flare and the subsequent outbreak of a magnetic storm.

The fluctuations ΔW of solar ionizing wave-radiation W were studied in their effect on the solar daily variation S . This may be schematically described as due to two ionospheric current-vortices with centers on the 11 o'clock meridian, progressing along about 35° latitudes, or, simpler still, as the magnetic field of a gigantic vertical horseshoe-magnet rotating around the Earth in the 11 o'clock meridian, with the south pole over 35° north latitude, and the north pole over 35° south latitude. These equivalent pictures illustrate those features in the daily variations of the north, east, and vertical-force components, X , Y , and Z , which express most clearly the intensity of S , and thereby ΔW , namely: near the equator, the daytime rise of X over the night-level; in northern middle latitudes, the daily wave in Y , with the morning maximum and the afternoon minimum, and the daytime decrease in Z ; in southern middle latitudes, the daily variations in Y and Z as in the north, but with reversed signs.

By induced currents in the Earth's interior,

S is magnified in X and Y and weakened in Z . This leaves, as most suitable for measuring ΔW , the daily ranges A (amplitudes) of X (or of the horizontal force H) near the equator, and of Y (or of the declination D) in middle latitudes. The annual variation of A is eliminated by computing for each calendar day a value of A corresponding to $R=50$; the standardized deviations ΔA from this value, expressed as multiples of their standard deviations, measure ΔW .

Studies according to this program were carried out for the horizontal intensity H at Huancayo (Peru), where S is of exceptional magnitude. The range A was defined as the excess of the 5-hour average 09^h to 14^h (standard time) over the night-level. This definition makes A satisfactorily independent of magnetic activity, that is, of corpuscular radiation P , up to the disturbance-level expressed by the international character-figure $C=1.1$; more disturbed days have so far been excluded from the computation. The lunar influence L appears in A as a wave with the period of half a month. In the average for the months November to February, near sunspot-maximum ($R=93$), this lunar semimonthly wave has its maximum, $A=149\gamma$, 4 days after new or full Moon, and its minimum, $A=99\gamma$, a quarter-month later. Elimination of L is therefore necessary in order to arrive at the range A_S of S alone and at the measure for ΔW . A table of monthly means for ΔW , 1922–1939, was thus obtained and correlated with the relative sunspot-numbers R . The correlation-coefficients found are the highest ever obtained between phenomena on the Sun and on the Earth; they are +0.92 for months, +0.97 for quarters, +0.984 for annual means. These values prove, incidentally, that the sunspot-numbers R are a very good measure for wave-radiation W , although their standard may not be so well defined as that of the magnetic variations.

Geomagnetic tides in the horizontal force at Huancayo. The lunar influence L on the daily ranges A of horizontal force H at Huancayo was studied in detail. In contrast with the solar daily variation S , L shows a large seasonal change, decreasing from Janu-

ary to June in the ratio 4 to 1. L changes with the sunspot-cycle nearly as much as S . Of the partial tides due to the changing distance of the Moon from the Earth, N_2 can be clearly recognized, but its effect, as compared with that of the main lunar semidiurnal tide M_2 , is not an increase of amplitude at perigee but a shift in phase-angle. The geomagnetic partial tides provide new observational material with respect to the tidal air-motions in the ionosphere and to the resonance-effects in the atmospheric tidal oscillations.

In the months December, January, and February, L is so large in relation to S that it can be recognized in the shape of the magnetogram for H on single days. Occasionally L luxuriates, so to say, and a model set of such "big L days" has been selected in which the lunar influence reaches 50 γ and more. Two conclusions can be drawn from the existence of such cases: The ionospheric air-motions must be dominated by tidal forces, much more so than the winds near the ground; and the strength of the L -currents in the ionosphere varies, on individual days, rather independently of the S -currents.

A more detailed analysis of L , in hourly means of H , was restricted to the three months December, January, and February. A new formula was derived for expressing the lunar wave, which seems more adequate than the phase-law based on the harmonic analysis. L is confined to the daytime. This points theoretically to a lunar semimonthly wave in the ordinary daily means of H of approximately 6- γ amplitude, which was actually traced in the observations. Furthermore, the suppression of L at night as well as its symmetry with respect to noon proves that the L -currents flow rather low in the ionosphere.

The computations on the lunar daily variations in magnetic and meteorological data, done at London under Chapman's direction, were continued, though somewhat less intensively since the outbreak of war. A considerable volume of results of this work now awaits preparation for publication.

MAGNETIC DISTURBANCES

The great magnetic storms of the present sunspot-maximum have all been accompanied by widespread disturbances of wire and radio communications; the unusually large one of March 24, 1940 even caused interference with electric power-systems. Study of the power-line effects reveals that they were caused by partial saturation of the transformer-cores due to large direct currents induced by the magnetic changes. Transformers in which direct-current components of this type were in opposition in individual coils were unaffected, but in certain regions, where other types of transformer were in use, relays and other protective mechanisms were operated by the storm. At a number of places where protective devices were unaffected, severe surges were recorded. Effects of this storm on power-systems extended throughout the northeastern United States and southeastern Canada, appearing in all localities simultaneously to within a minute. The earth-potentials needed to produce these large direct-current components exceed any previously recorded. Calculations of the magnetic changes necessary to produce such earth-potentials were made. It was found that sudden magnetic changes in the region of the zone of great auroral activity need only be somewhat greater than the greatest changes yet observed in order to produce the effects.

Study of great magnetic storms, as recorded at many magnetic observatories, suggests that with increasing amplitude of the perturbations there is also an increase in the rate at which a storm passes through its phases, both for the component dependent on universal time and for the component dependent on local time.

A wide-range magnetic recorder was installed in the Standardizing Magnetic Observatory at the main laboratory of the Department at Washington, D. C., during April 1940. Although regular magnetic observations had been made at Washington in earlier years, this practice had been abandoned owing to artificial disturbances produced by electric cars. Such artificial disturbances, however, are of minor consequence for a wide-range

magnetograph which is designed to supply complete records of the greatest magnetic storms. The increasing importance of recording such storms has been emphasized by the occurrences of the present sunspot-cycle, when extensive interference with electric communication- and power-systems has been experienced.

The work on the disturbance-field of four moderate magnetic storms (Year Book No. 38, p. 66) was extended and atmospheric current-systems were estimated for a number of additional hours of storm. During the initial phase of the storm of October 14, 1932, the intense polar circulations of current characterizing the main phase of storms were absent. As seen from above the geomagnetic north pole, the current-circulation was mainly directed eastward above the Earth, with an anticlockwise circulation centered south of the pole and on the daylit side of the Earth. Chapman noted that this vortex in the northern hemisphere was in good qualitative agreement with the theory of the initial phase of storms as developed by him and Ferraro; the vortex of current would be induced, in the face of an advancing solar stream of particles, by the geomagnet. Sufficient data for the southern hemisphere were not available to determine the possible presence there of a high-latitude vortex of current circulating in the opposite sense, as required by theory. An investigation is under way to check the agreement between theory and observation, using more extensive data for sudden commencements and the initial phase of storms.

The current-systems for an hour of the initial and main phase of the storms were analyzed into their component D_{st} - and S_D -parts. The current-systems for each phase estimated for the storm-time component D_{st} were the same in general type but opposite in sense, although much stronger westward currents flow along the auroral zone during the main phase. In the case of the disturbance daily variation S_D , the chief feature found during the initial phase was a great vortex of current over the daylit part of the northern hemisphere circulating anticlockwise as seen

from outside. This circulation was very different from the corresponding S_D -circulation for an hour of the main phase, which showed characteristics agreeing closely in magnitude and sense with those of the current-system previously deduced by Chapman for the (averaged) main phase of 40 storms. It thus appeared that the current-systems deduced for individual hours of the main phase of moderate storms resemble fairly closely those found for the main phase averaged for many storms. During the main phase of storms the electric currents responsible are likely to flow near the *E*-region of the atmosphere, though there may be a part in the form of an equatorial ring-current at a distance of a few earth-radii, a conclusion arrived at through previous studies. The initial phase of storms has not yet been subjected to systematic study, and in the one case of the storm of October 14, 1932, the suggestive agreement between theory and observation would, if real, place the probable origin of at least part of the currents beyond the atmosphere during the early hours of storm.

The cooperation between Chapman and Dr. V. C. A. Ferraro on the theory of magnetic storms was continued, and a further paper on the subject was completed; it gives further confirmation to the authors' theory of the first phase of a magnetic storm.

The new analysis of the daily and irregular magnetic variations by Chapman and J. Crank had to be interrupted because of the war. Consideration of what had been done led Chapman to an examination of several general aspects of the geometry of isomagnetic charts, and the first of a short series of notes on the subject was prepared. It is expected that these notes will be of future service in the construction of all kinds of isomagnetic charts and diagrams of electric current-systems.

An application of the Gaussian method to the mean hourly disturbance-field of a magnetic storm was made (Vestine). Suitable coordinate nets were constructed permitting fairly speedy evaluation of the surface-integrals. It was found that about 60 per cent of the observed surface-field is of external

origin, except in the region close to the auroral zone, where greater variability is shown. Estimates were also obtained of the error introduced in the use of plane-earth approximations in polar regions.

ARCHIVES OF MAGNETIC RECORDS

Additional miniature-film records of magnetic records made during the Second International Polar Year were received for the archives maintained at the Department. The Polar-Year records are thus virtually complete and furnish a valuable assemblage of data which are immediately available for investigations in this country. Although the hazardous conditions existing abroad may result in destruction of many of the original records, the fruits of this cooperative international endeavor to obtain magnetic records from polar regions are certain of preservation through the existence of these archives in this country.

UPPER ATMOSPHERE

An experimental investigation of the upper atmosphere was made (Johnson, Hopkins, Mock) by measuring the light scattered from the beam of a modulated searchlight. Using refinements of technique, it was possible to detect an amount of light of 10^{-14} watt in the presence of a background light of 10^{-10} watt. With a carbon arc, a 24-inch transmitting mirror, and a 30-inch receiving mirror, the scattered light was detected from heights of 40 km. The resolution was determined by the intersection of the searchlight-beam and the angle viewed by the photocell. The results show distribution of temperature and pressure in agreement with the observations of Hulbert, with an estimated temperature of -55°C at 40 km; they indicated that with 60-inch mirrors an ultimate height of 70 to 90 km is possible and that the distribution of some of the atmospheric constituents, especially ozone, can be determined. Work was begun in June 1940 (Aronson, Johnson) on an experimental program using 60-inch mirrors kindly loaned by the U. S. War Department.

The work by Chapman and A. J. Majid Mian on Fourier and spherical harmonic expressions for the radiation-absorption and the ion-content at different levels in an ideal ionosphere was completed. (For this work the junior author was awarded the London degree of Doctor of Philosophy.) It is hoped later to prepare an account of this work for publication.

INSTRUMENTAL DEVELOPMENTS

Electromagnetic method. The work on the CIW primary magnetic standard (Johnson) consisted primarily in the accurate measurement of the mechanical dimensions of the coils to one part in a million and the construction of the complete instrument. Special measuring machines and measurement-standards, necessary for the unique requirements for measurement, were made. These measurements include those for wire-diameter, coil-pitch, and coil-diameter. The wire-diameter was measured with a precise thermionically operated mechanical micrometer and a set of special gauges loaned by the National Bureau of Standards. No ellipticity of the wire and no significant change in diameter over the entire length of the winding were observed with an estimated probable error of less than 0.05 micron. For the difficult measurements of pitch, the room-temperature was maintained to $\pm 0.1^\circ\text{C}$ for determinations at 20°C and 28°C to yield the temperature-coefficient. The results of several thousand measurements with line-standard and especially constructed cathetometer showed that variation in pitch was negligible and temperature-coefficient was about that of the pyrex coil-form; precision is estimated at ± 0.25 micron. The measuring engine for determination of coil-diameter and a precise spherical-ended standard are completed; the latter is spherical to better than 0.1 micron, according to tests of the National Bureau of Standards.

CIW induction-variometer. Operation of

the CIW induction-variometer was continued by the staff of the Cheltenham Magnetic Observatory of the U. S. Coast and Geodetic Survey through the first half of April 1940, thus concluding over four years of experimental operation. It was then removed from Cheltenham and installed as the vertical-intensity instrument of the wide-range magnetograph at the laboratory in Washington.

PUBLICATIONS

Publications relating to the geomagnetic researches are listed in the bibliography at the end of this report. Chapman and Bartels devoted much time to their text *Geomagnetism*, published by the Oxford University Press; despite delays caused by the war, the printing was completed in June 1940.

Presidential addresses were made before two associations of the International Union of Geodesy and Geophysics in September 1939, namely, "Tides in the air," by Chapman, and "Trends of research in terrestrial magnetism and electricity," by Fleming.

Bartels presented the following papers: "Geomagnetic tides at Huancayo," April 24, 1940, before Section of Terrestrial Magnetism and Electricity of the American Geophysical Union; "The needle in the haystack, or statistics in geophysics," March 21, 1940, before District of Columbia Branch of American Meteorological Society; and "Magnetic changes caused by the Sun and the Moon," May 4, 1940, before the National Capital Amateur Astronomers' Association. McNish took part in an extemporaneous discussion of the great magnetic storm in progress in a nation-wide broadcast on March 24, 1940. He also addressed the Edison Electric Institute at Chicago on "Magnetic storms" (May 7, 1940), the Philosophical Society of Washington on "The geomagnetic field and its variations" (March 2, 1940), the Washington Physics Colloquium on "Theories of the Earth's magnetism" (April 10, 1940).

TERRESTRIAL ELECTRICITY

In both branches of this subject, namely, atmospheric electricity and geoelectricity, a large share of the time of the members of the section is required for checking, controlling, and reducing data received from the observatories and for putting these in suitable form for final studies and publication. More information about this is given in the report on observatory-work. Special investigations, experiments, instrumental developments, etc., in progress at this Department during the report-year are outlined in the following paragraphs. The members of the staff participating in these are Gish, Rooney, Sherman, Torreson, and Wait.

ATMOSPHERIC ELECTRICITY

The broader objectives of investigations of this class of phenomena have been outlined in the introductions to the reports in Year Books Nos. 37 and 38. One of these objectives is to obtain a satisfactory understanding of the nature and origin of the "supply-current," that current which in an undetermined manner supplies negative electricity to the Earth at a rate of about 1800 amperes and thus maintains a negative charge on the surface in all areas where fair weather prevails. A measure of this current is obtained only indirectly from measures of the current which flows from air to Earth in such areas. This, however, depends to some extent upon meteorological and other more or less local factors which have to be taken into account in attempts to arrive at a measure of the supply-current. In order to take account of these factors various auxiliary studies are made which often have interest in themselves and occasionally have specific bearing on other aspects of geophysics and practical affairs. Studies of this kind are accordingly prominent in this report.

Diurnal and annual variation of the atmospheric-electric conduction-current at College, Alaska. Although it was reported last year that the average conduction-current at College, Alaska is practically the same as that indicated by measurements made at sea dur-

ing cruises of the *Carnegie* and that, on the average for the year, the diurnal variation of this element closely resembles that found at sea, a continuation of that study has shown that when the data for the winter and summer seasons are separately considered, the ratio between the current at College and that at sea undergoes a significant diurnal variation. The character of the latter in summer is very different from that in winter, tending to have a double period in the former season and a single period with about half the range in the latter season. Several interpretations of this which are likely first to come to mind have been shown to be inadmissible, and some alternative interpretations, which require verification in the future, have been considered in a paper by Gish and Sherman (*Terrestrial Magnetism*, vol. 45, pp. 173-190, 1940).

Just as the diurnal variation of the atmospheric-electric conduction-current gives an indication of a diurnal variation in the supply-current, when effects tending to distort the former are duly considered, so also one may examine the annual variation of the conduction-current for an indication of the annual variation of the supply-current. The general character of the diurnal variation of the supply-current is now generally thought to be well established, and quantitative representations of this are viewed with confidence, but the situation with respect to the annual variation is unsatisfactory. Although it was reported some years ago (Wait) that the character of the diurnal variation of the potential-gradient, as indicated by data obtained at sea up to the end of cruise VI of the *Carnegie*, apparently undergoes an annual variation, and although this conclusion seemed to be supported by data obtained on cruise VII, the quantity and distribution of data and other circumstances were such that there was some ground for doubting the significance of this indication. A re-examination of this question by approved statistical methods, started during the year (Sherman), seemed justified because it is thought that the

annual variation in gradient at sea and that in the conduction-current there are practically alike; observations of the air-conductivity there showed no significant annual variation and little other systematic variation. The results of that analysis were also desired for comparison with those obtained from a corresponding analysis of the conduction-current at College. Although the analysis is not complete, there is already good indication that the change in character of the diurnal variation during the year is significant at sea and at College and that this change is significantly similar at the two places. If the same correspondence is eventually found for a number of other places, well distributed in latitude, one may then begin to regard the annual variation of conduction-current at these places as chiefly an expression of the annual variation in the supply-current.

Analysis of atmospheric-electric data at Watheroo for 1924-1934. Analysis of the 11 years of data on potential-gradient and positive and negative conductivity at Watheroo was begun by Wait and Torreson. Summaries, month by month, for "all complete days" and "selected days" for each of the three elements for the 11-year period were prepared, giving diurnal-variation curves for each month, representing the mean curve for the period of observation. These summaries were then used to compute diurnal-variation data for air-earth currents for each month. Finally, harmonic analyses were made of the data for each month for "selected days" for potential-gradient, positive and negative conductivities, air-earth current, and ratio and difference of positive and negative conductivities. For the 24-hour component it is of interest to note the following points:

a) In potential-gradient, the maxima in the 8 months from September to April fall between 21^{h} and $23^{\text{h}} 120^{\circ}$ east meridian time (13^{h} to 15^{h} GMT), which is in good agreement with the universal-time variations found over the ocean, but the 4 months from May to August have their maxima between 15^{h} and $17^{\text{h}} 120^{\circ}$ east meridian time, which is not in accord with the results over the oceans.

b) The positive conductivity has its maximum in each of the 12 months very close to

$06^{\text{h}} 120^{\circ}$ east meridian time, and the maximum in negative conductivity falls about 1.5 hours later, at $7^{\text{h}} 5$.

c) The ratio of positive to negative conductivity has its maximum in all months at approximately $24^{\text{h}} 120^{\circ}$ east meridian time, and the difference between the two conductivities has its maximum at about 01^{h} .

d) The computed air-earth current has maxima for the 7 months from October to March lying between $2^{\text{h}} 5$ and $4^{\text{h}} 5 120^{\circ}$ east meridian time; September has its maximum at $5^{\text{h}} 5$, and the 4 months from May to August have their maxima between $6^{\text{h}} 5$ and $7^{\text{h}} 5$.

The 12-hour component of the diurnal variation has also been obtained from the harmonic analysis of the several elements, and in each case it contributes but a small part to the observed diurnal variation.

The monthly mean value of potential-gradient for the 11-year period 1924-1934 at Watheroo changes considerably through the year. For the 8 months from September to April it is between 85 and 95 volts per meter, whereas for May and June it is 70 volts per meter and for July and August 80 volts. Study of the rainfall-data for Watheroo reveals that the months May to August are the雨iest of the year (two-thirds of the annual rainfall occurs in these months), and it is in these months that the monthly mean values of potential-gradient are lowest and the 24-hour component of the diurnal variation in this element is not in phase with the recognized universal 24-hour component which prevails over the ocean. In these months meteorological conditions doubtless play an important part in determining both the magnitude of the potential-gradient and the character of its diurnal variation.

A second interesting point is the difference in phase between the 24-hour component of the diurnal variation of positive and that of negative conductivity. The fact that the negative conductivity reaches its maximum 1.5 hours later than the positive deserves careful study, because an understanding of the cause of this will help to clarify knowledge of ionic equilibrium in the atmosphere.

The magnitude of the air-earth current, which is of considerable interest, is derived

from the monthly summaries of the computed current. The range in monthly mean value is from 8.0 to 11.2×10^{-7} esu, with low and high values in February and July, respectively. In general, the wet months from April to September have the higher air-earth currents, and the dry months have the lower currents.

From the summaries of potential-gradient, comparison of "all complete days" with "selected days" shows in the months from December to March a prominent smoke-effect in the "all complete days" during the night hours. How completely the smoke-effect is avoided in the "selected days" is not known, but it is apparent that much of it has been. One of the papers presented during the year discussed this smoke-effect and other meteorological effects on the electrical condition of the lower atmosphere.

Effects of meteorological factors upon the atmospheric-electric elements at Watheroo and Huancayo. Further discussion (using added material) of the pronounced smoke-effect at Watheroo, where the smoke remains at low levels, and of the effect at Huancayo of large concentrations of condensation-nuclei, which must be present to considerable heights, concerned the high correlation found at Watheroo between fluctuations in wind-velocity and fluctuations in potential-gradient and conductivity. The fluctuations in potential-gradient, conspicuous feature of the atmospheric-electric records, have periods of only a few minutes and have amplitudes of about 25 per cent of the value of the prevailing potential-gradient when the wind-velocity is 5 miles per hour, and 50 per cent when it is 10 miles per hour. The fluctuations in conductivity are much smaller but vary in a similar manner with changes in wind-velocity. The function of the wind in producing fluctuations in the atmospheric-electric elements is obscure, and it is possible that the wind is merely correlated with some more significant factor which is not yet revealed.

Ionic equilibrium in the atmosphere. The electrical conductivity of the air depends chiefly upon the concentration of small ions of molecular dimensions. Changes in con-

ductivity result in changes in potential-gradient and other electrical aspects, and on this account an understanding of the factors which determine the concentration of small ions is important to an understanding of the resultant phenomena. For a state of equilibrium, the concentration of small ions is expressed by a relation which is obtained by taking the rate of ion-formation equal to the sum of the rates of ion-destruction and ion-migration. The advantage to investigation of having such a relation is obvious, and considerable advantage has already been realized, but an adequate approach to that goal has not yet been made. In a critical review completed during the report-year and reported at the Washington meeting of the International Union of Geodesy and Geophysics, Gish and Sherman compared the values reported for the parameters which occur in such relations. The striking diversity of these values, though not definitely assignable to particular factors, may in part be attributed to a difference from place to place in the character of the nuclei of condensation and of the large ions formed from these at the expense of small ions, but there appears to be evidence that a considerable part of the diversity is associated with the method of measurement and with that used in evaluating the parameters. Furthermore, it is probable that a state of perfect ionic equilibrium never exists in the atmosphere, but that the balance tips first one way and then the other. Because of this, the concept of equilibrium applies to the average rather than to the specific state, and accordingly the measurements which are used in evaluating the parameters of the equations of ionic equilibrium must constitute an adequate sample and must be combined with due regard to the principles of statistics. The latter point is emphasized by the observation that in one of the few cases for which a full report of the primary data is available, it is found that the values of a parameter determined by two different methods of combining the primary data differ by 25 per cent.

Although the situation with respect to the parameters is not satisfactory, it is evident from this study that the relations for ionic

equilibrium, even in the simple form usually employed, express the average relation between the several elements with a fair degree of approximation at the majority of places, but that the set of parameters required differs considerably from those which have generally been used.

An investigation of the ratio of the concentration of the uncharged to that of the total nuclei (N_o/N_a) made during the past year (Sherman) provides additional ground for confidence in the validity of the equilibrium-relations for a rather wide range of conditions in the vicinity of Washington, namely, for air in a closed room in the laboratory, for air in the city, both in daytime and at night, and for air in the open country. No significant change in that ratio was revealed by a careful statistical analysis. That analysis is recommended for consideration by others who undertake such work in the future. Some investigators have reached conclusions which directly or indirectly imply that this ratio depends upon the concentration of nuclei and upon their size and nature, and that there is a considerable variation from night to day. The results outlined above indicate that those conclusions are not as generally applicable as may have been thought heretofore. Interest in undertaking this investigation was in part stimulated by the fact that the value of (N_o/N_a), namely, 0.73, found from a series of measurements made at Washington several years ago (Wait and Torreson) was greater than that found at any other place by other observers and was nearly 1.5 times the value that was generally regarded as most representative. An equally large value (0.75) was found in this more extensive recent investigation. This signifies that the rate at which small ions in a given concentration combine with charged nuclei (large ions) is about six times that for combination with uncharged nuclei in the hypothetical case that the charged and uncharged nuclei occur in the same concentration. This also implies the same type of modification of the parameters which it was earlier found (Gish, annual report for 1937-1938) would bring the equilibrium-relations and the observations

into agreement in several cases which had been cited by one investigator in support of his claim that the equilibrium-relations are not valid in the present form. Obviously the present investigation provides further evidence against that claim.

The form of the equilibrium-relations usually employed is admittedly a first approximation in which certain factors are neglected. A consideration of these neglected factors is definitely required in certain circumstances. Thus it was found (Gish and Sherman) that when a term which depends upon the drift of small ions in the electric field is included, the relations for ionic equilibrium give a satisfactory quantitative account of the ratio of positive to negative conductivity and the dependence of that ratio upon the potential-gradient at College, Alaska, in winter when the air is very quiet. When the air is not quiet, turbulent stirring may effect a systematic migration of ions, both large and small, and of nuclei. Terms expressing the role of this factor may also be included in the differential equations of ionic equilibrium. Solutions of these more complete equations have been found only for special cases. One such solution, in which the total conductivity was assumed to be constant with elevation from the Earth's surface, was reported by Gish at the annual meeting of the American Geophysical Union in 1940. This solution shows that the observations made by Hogg of the vertical distribution of positive and negative conductivity in the first meter from the Earth's surface at the Kew Observatory may be quantitatively accounted for by the more general form of the equations of ionic equilibrium, provided the nuclei at the place of observation come chiefly from a distant source.

The rate of ionization in the atmosphere plays an important role in determining the state of ionic equilibrium. Measurements of this element appear to be the least satisfactory of those which have to be used in evaluating the parameters in the equations of equilibrium, and some of the diversity in the values published for those parameters may be attributed to this fact. In an endeavor to ob-

tain a better estimate of this element at Washington, measurements have been made for several years using a so-called "thin-walled ionization-chamber" designed for continuous registration.

In last year's report some interesting results obtained with the thin-walled ionization-chamber for different concentrations of large ions in a closed room indicated that the measured ionization diminished when the concentration of large ions in the air of the room increased. Among various explanations for this phenomenon, it was suggested that large ions fall to the floor, carrying radioactive matter collected on them out of reach of the apparatus. To test this possibility, a wide rim was attached around the base of the ionization-chamber to catch any large ions that might fall out of the air above it. Radioactive material caught on the rim would, however, still be near enough to the chamber-wall to produce ions inside the chamber, and would diminish or even reverse the effects originally found. Furthermore, with time, the accumulation of material on the rim might be expected to produce an increase in the ionization in the apparatus. Analysis of the records obtained with the rim in place showed none of these effects, and hence there is no support for the suggestion that radioactive material falls to the floor attached to large ions. The cause for the phenomenon thus remains unknown and calls for further experimentation.

The rate of combination of large ions is usually thought to be negligibly small in relation to other terms in the equations for ionic equilibrium, but that opinion is based chiefly on a single set of experiments made many years ago on ions from gas flames. A joint paper on this subject by Wait and Torreson was presented by Wait before the meetings of the American Physical Society in April 1940. The importance of a knowledge of the value of the recombination-coefficient between large ions of opposite sign, which enters into equations of ionic equilibrium in the atmosphere, has been discussed by Gish (*Terrestrial magnetism and electricity*, p. 183, 1939). He expressed the hope that the wide

difference between the value deduced by Hogg and that obtained experimentally by Kennedy from measurements on ions from a gas flame would stimulate investigators to repeat Kennedy's measurements. During the past year, Wait and Torreson repeated those experiments, obtaining important and significant results which must, it appears, be taken into account when considering equilibrium-conditions for ions. Kennedy's value for the coefficient was 0.63×10^{-9} , whereas Hogg considered the value to be about 17×10^{-9} . Wait and Torreson found that the value of the coefficient did not remain constant, but rapidly diminished from the time the ions were first formed. The initial value was approximately that given by Hogg, but in 90 minutes it had diminished to about the value given by Kennedy. In view of the fact that the coefficient decreases with increase in size of the ions, the reason for the diminution in the value of the coefficient for large ions seems clear. There is, no doubt, an increase with time in the average size of the large ions in a given volume of air, for each time a pair of such ions combines, the resultant ion is probably larger. Sufficiently large concentrations of large ions were used in the experiments (initial value about 300,000 per cubic centimeter) to ensure that recombination of large ions of opposite sign would be the only important factor in causing the diminution in ion-concentration in the volume under observation during the period of experiment (*Physical Review*, vol. 57, p. 1071, 1940).

The concentration of condensation-nuclei over the North Atlantic Ocean, measured by Davies on a round-trip cruise from North America to England in August and September 1936, was analyzed and reported by Wait during the report-year. The mean of 186 sets of measurements is 751 nuclei per cubic centimeter. The value is usually relatively high to the leeward of land, even for distances as great as 200 miles from shore. The mean for 123 sets observed in the eastern two-thirds of the region covered, namely, 960 nuclei per cubic centimeter, was just one-half that for 63 sets observed in the western third. This

distribution is probably effected by the supply of nuclei from the North American continent, due to the prevailing westerly winds in this latitude.

Some much needed supplementary atmospheric-electric observations could now be obtained with equipment of tested design. The urgent need of such observations has been further emphasized during the past year, the point being that in the interpretation of many features of the data which are now being obtained at observatories, the area of speculation remains too large. A paper in which this matter was stressed was presented at the Washington meeting of the International Union of Geodesy and Geophysics (Wait and Torreson). The plan for improving this situation is that for a period of one year at each observatory, successively, the present registrations (potential-gradient, positive and negative conductivity) be supplemented by simultaneous registrations of the rate of small-ion formation, and of the concentration of large, intermediate, and small ions, with equipment designed to be readily moved and quickly adjusted for operation. The information to be obtained from this supplementary program would serve the following purposes: (a) to make quantitative tests of interpretations which at present can be only tentative; (b) to provide better quantitative information about the parameters which occur in the equations for ionic equilibrium in the atmosphere and thereby facilitate the interpretation of atmospheric-electric phenomena generally; and (c) to make more satisfactory discrimination between the electrical phenomena of local and of universal origin, in order that data pertaining to the latter may be used to determine more definitely the characteristics of that fundamental element of atmospheric electricity, the supply-current. The scientific returns to be expected from the present limited program are practically all realized, but one may look with confidence for important additional returns from a short period of operation of the proposed amplified program.

A "creep" in the setting of some electrometers of the portable torsion-type at rela-

tively low sensitivity was examined by Gish and Sherman in the hope of finding the cause of this effect. In one instrument, which was being considered for use in biological investigations, and which showed an exceptionally large creep, it was found that the greater part of that effect was eliminated when a capsule of radium salt was placed near the electrometer. This together with other tests showed that the electrical conductance of the needle, probably near the ends, was inadequate. It appeared, however, that a minor but detectable component of the effect was caused by some other factor. The latter was not investigated experimentally, but calculations indicate that it may be attributed to a defect in the method of supporting the torsion-fiber. Those calculations were qualitatively consistent with results of tests made on eight electrometers by Israël (*Zeitschrift für Instrumentenkunde*, vol. 51, pp. 464-472, 1931). Although the ideal torsion-type, postulated by theory, would be electrically stable at a higher voltage-sensitivity than the single-fiber type, that ideal is apparently far from being realized in portable torsion-type electrometers available in this country. This examination indicated that some improvement in the technique of applying the conducting layer on the needle and in that of mounting the torsion-fiber is required in order to make this type comparable with, or superior to, the single-fiber type which has been in use for years in this laboratory.

Error in measurements of the concentration of condensation-nuclei was found by Sherman to arise in an unexpected way. Such measurements are usually made with a so-called Aitken counter, which is essentially a small hand-operated expansion-chamber with a small expansion-ratio. In this it is essential that there be no leakage of air from outside into the chamber during an expansion, for such leakage may introduce nuclei in addition to those brought in with the measured sample of outside air, thereby erroneously increasing the "count." A leak of this character is revealed by droplets continuing to fall on the counting stage after repeated expansions. However, a contrary indication can no longer

be regarded as a sure criterion of freedom from sufficient leak to falsify the count in serious degree. This was shown by the following observation. Measurements made nearly simultaneously with two counters, both apparently in good order, differed systematically, the mean for one being about one-half that for the other. Tests with a manometer showed a leak in the one which gave the smaller count. After this defect was remedied, the results from the two counters agreed. Now that errors of such origin are recognized and understood, it is seen that they may be avoided by setting the cock in such a way that the pressure in the chamber is brought to that of the atmosphere each time before the sample of air is admitted.

Electrical phenomena associated with the evaporation and condensation of water. Dr. Ross Gunn, Research Associate, continued his experimental study of the electrical phenomena associated with the evaporation and condensation of water. He developed a new apparatus suitable for the study of contact-potentials, or contact-potentials with superposed free charges, which extends a method previously outlined by him in the *Physical Review* (vol. 40, p. 307, 1932). Using the new apparatus, it has been observed that a discontinuity in contact-potentials of 0.26 volt occurs when a frozen raindrop melts and a water-surface is formed thereon. The outer surface becomes more positive on melting or more negative on freezing. This phenomenon may play a considerable part in the phenomena of electricity of thunderstorms. The measurements are tentative and will be checked with more satisfactory apparatus now under construction.

Cooperation in atmospheric-electric work of other investigators. A portable apparatus for use in determining the ratio of the concentration of the uncharged to that of all nuclei of condensation in the atmosphere was designed by Gish and constructed in the Department's instrument-shop for use on the National Geographic Society—University of Virginia South Seas Expedition. When that expedition was indefinitely postponed because of developments in Europe, this apparatus

was used by Sherman for the series of measurements mentioned earlier in this report.

As part of the cooperation with the Geological Laboratory in volcanological investigations, a portable "ionization-meter," designed by Gish following the general features of the "ionization-recorder" of Wait and McNish (*Monthly Weather Review*, vol. 62, pp. 1-4, 1934), was constructed in the instrument-shop, and calibrated and tested, so far as time permitted, by Sherman and Gish; and, since this could not be completed before Dr. Zies, who was to use it, left for Guatemala, a description and directions for its use were written. The ionization-chamber is in the form of a circular cylinder about 36 cm long and 22 cm in diameter. The cylindrical wall consists of cellophane, about 0.025 mm thick, supported on an open-mesh brass screen. A considerable proportion of the alpha rays from the radioactive matter in the outside air can pass through this wall and produce ions inside the chamber. Tests in the laboratory indicated that of the total ionization inside the chamber (about 15 ion-pairs per cubic centimeter per second), 22 per cent was due to alpha radiation coming from radioactive matter in the air outside, the rest being due to gamma radiation, chiefly from radioactive matter in the Earth, to cosmic radiation, and to an undetermined but probably small "residual ionization" caused by radiations from radioactive impurities contained in the materials from which the walls of the chamber are made. Below the ionization-chamber is the electrometer used in measuring the charge given, by the ions collected, to an insulated rod which stands along the axis of the ionization-chamber. Below the electrometer is a compartment for batteries, switches, etc. These parts are all rigidly joined together into a unit with over-all height of 73 cm which fits into a cylindrical metal carrying and protecting case of about the same height and about 26 cm diameter. If in part of the measurements this case is left in place around the ionization-chamber, the alpha rays from outside are absorbed by it so that then only the ionization due to gamma rays, cosmic radiation, and the resid-

ual ionization are measured. (Ionization from beta rays in the atmosphere is estimated to be only about 3 per cent of the total.) The difference between measurements made in this way and those made with the case completely removed is then a measure of the part attributable to alpha rays. According to estimates made by Professor V. F. Hess, of Fordham University, alpha rays produce about 92 per cent of that part of the ionization which depends upon radioactive matter in the air, and gamma radiation produces about 97 per cent of that attributable to radioactive matter in the Earth. On the basis of these estimates it is expected that from a survey which can be made with this apparatus it should be possible to obtain worth-while information about the relative distribution of radioactive matter both in the air and in the Earth near the surface.

Several visits to the Department during the year by Professor Hess were occasions for conferences which were particularly stimulating because of his years of active interest in problems of atmospheric electricity. Arrangements were made for effecting some improvements in two nuclei-counters, belonging to him, by an outside instrument-maker working in our shop under the supervision of Steiner. These were then tested and compared with DTM counter no. 6 by Sherman. Nathan Cornfeld, a graduate student with Professor Hess and instructor in physics at Long Island University, conferred twice during the year with members of the staff regarding an investigation of condensation-nuclei in the atmosphere which he has undertaken under the direction of Hess.

An ionium-coated "collector" was supplied to Professor H. T. Stetson, of Massachusetts Institute of Technology, for use in measurements of the potential-gradient in the atmosphere.

Gish served on the Subcommittee on Lighting Hazards to Aircraft, of the National Advisory Committee on Aeronautics.

GEOELECTRICITY

Work pertaining to the electrical phenomena in the Earth was confined chiefly to

examinations for controlling the operations at the observatories, making final check and reductions of tabulations of these as received, and in general putting these in form suitable for further investigation and for publication (Rooney). Two papers, one on "Initial geo-electric work at volcano Santa María" (Gish), the other on "Variation in earth-current activity with sunspot-cycle" (Rooney), were completed for publication and presented at the Washington meeting of the International Union of Geodesy and Geophysics. The substance of these was reported last year.

Resistivity-survey at Quezaltenango, Guatemala. In connection with the extensive volcanological investigation which the Institution has supported and carried on for several years in Guatemala, the Department in cooperation with the Geophysical Laboratory undertook a series of earth-resistivity measurements to determine the probable depth of the extensive deposits of volcanic ash on the upland plains of that country. The main survey was made on the plain just north and east of the city of Quezaltenango, approximately 11 km from the volcano Santa María. The survey covered an area of about 30 square km, on which 20 lines, mostly 1200 m long, were run, thus securing records of the average resistivity to depths of 400 m (1300 feet).

The surface-soil of this plain consisted almost exclusively of fine pumiceous material, and the object of the investigation was to determine, if possible, the depth of these deposits. Measurements of the specific resistance of the ash made at a dozen or more stations in road-cuts or on natural escarpments showed that, like most overburden materials, its resistance depends almost entirely on the amount of moisture it contains. At stations near to, and practically at the same level as, the Samalá River, two branches of which follow tortuous courses through the plain, the recorded values of resistivity remained fairly constant at between 4000 and 6000 ohm-cm, regardless of the electrode-separation or depth of soil included, down to the maximum depths of 300 or 400 m. This value, then, is undoubtedly representative for the volcanic ash when wet.

At all other stations the recorded resistivity-values, starting rather low because of a superficial layer of moist arable soil, increased sharply with depth as more and more dry ash was included in the measurements, until the underground water-level was reached. This occurred at a depth of anywhere from a few meters to 100 m or more, depending on the location and elevation of the station. Following the maximum point on the curve, which corresponds to the underground water-level, the recorded values showed a slow and steady decrease toward the values recorded in the river-bottom. At no place, except possibly at one or two stations near the edges of the plain where topographical irregularities make the interpretation of the results somewhat uncertain, was there any indication of a definite change in structure to depths of 400 meters. At one station in the center of the plain the measurements were extended to depths of 500 and 600 m (1640 to 1970 feet) without any change in the general trend of the results.

Practically no information is available about the structure underlying the ash. It is, however, almost certain that a change of structure from the well-moistened ash to a dense igneous rock or even a well-consolidated sedimentary should have been revealed by a second change in the trend of the recorded values. It must therefore be concluded either

that the ash-deposits are thicker than the depths to which the measurements were extended, 400 m in most cases, or, as is somewhat less likely, that the underlying rock is unusually porous and has practically the same resistivity as the wet overburden.

A notable feature of the survey was the uniformity of the results over most of the area surveyed. Aside from the shift in the position of the maximum point, which in a number of instances could be readily correlated with the underground water-level by reference to near-by wells, all the curves obtained on the flat central section of the plain were almost identical.

PUBLICATIONS

Publications during the report-year relating to terrestrial electricity are listed in the bibliography at the end of this report. The following papers (not yet published) were presented at the annual meeting of the American Geophysical Union in 1940: "Distribution of electric elements in the air near the Earth's surface," by O. H. Gish; "Total and uncharged nuclei at Washington, D. C.," by K. L. Sherman. G. R. Wait and O. W. Tresson, at the Washington meeting of the American Physical Society in April 1940, gave a paper on "Recombination of ions from gas flames."

INVESTIGATIONS OF THE IONOSPHERE AND ITS RELATION TO PROBLEMS OF TERRESTRIAL MAGNETISM

Ionospheric investigations of the Department are directed toward disclosure of fundamental relations between electrical conditions in the Earth's outer atmosphere and geomagnetic changes which arise there. It is known from the fundamental theoretical work of Gauss, as extended by Stewart and Schuster, that ephemeral changes in geomagnetism must have their origin, in part at least, in the outer atmosphere. Direct investigation of outer atmospheric regions by radio methods, initiated by the Department in 1925, has demonstrated experimentally the existence of ionized layers of a nature that could account

for certain of the geomagnetic fluctuations. The character of these highly ionized regions, however, has been found to be much more complicated than was originally supposed, with three major ionized strata in evidence. The problem has therefore resolved itself into a careful examination and analysis of the nature of each of these regions in order that the origin of geomagnetic fluctuations may be localized and examined quantitatively and their sources disclosed.

Besides their purely geomagnetic significance, the ionospheric investigations of the Department have collateral importance to

other fields of science and to radio communication. Since radio wave-transmission over great distances depends upon reflection of radio waves from the ionosphere, detailed definition of ionospheric structure and variation is of fundamental importance to this phase of communications engineering; information of this kind is now being obtained. Furthermore, ionospheric measurements bid fair to yield a new and more accurate index for measuring variations in solar radiation than has been available heretofore; this provides a new tool for study of the physics of the Sun. The investigations have also provided a tool for attack on certain problems of pure physics.

The ionization of the Earth's outer atmosphere is produced chiefly by emanations from the Sun. These can be divided into two classifications, namely, (1) ultraviolet ionizing radiation traveling toward the Earth at the velocity of light, and (2) corpuscular radiation probably consisting of atoms or molecules traveling at a considerably lower velocity than that of light because of their relatively great rest-mass. There is also the possibility of ionization by streams of corpuscular radiation not originating from the Sun, but bombarding the Earth as it intersects these moving streams in space. Radiations such as stellar ultraviolet and cosmic rays can account perhaps for only 1 or 2 per cent of the observed ionization. One of the great problems of ionospheric investigation is to determine the relative amount and importance of these sources, both corpuscular and ultraviolet, and to determine the character of the corpuscular radiation.

Probably the greatest forward step in the investigations has been the development by the Department of an apparatus for continuous recording of ionospheric structure. As described in previous annual reports, this has made possible the collection of continuous data concerning ionospheric changes at several locations, in particular at the Department's two magnetic observatories, from which we have the longest series of continuous ionospheric data anywhere obtainable (Huancayo Magnetic Observatory since 1937 and

Watheroo Magnetic Observatory since 1938). It is planned to extend the work over a sunspot-cycle, so that the principal characteristics of the ionized regions may be quantitatively defined through a wide range of solar changes. These data are proving invaluable not only in providing information for solution of the problems at hand, but also in disclosing many new factors heretofore unrecognized.

Previous reports of ionospheric investigations at the Watheroo and Huancayo magnetic observatories, taken together with the work of investigators in the northern hemisphere, have served to delineate qualitatively the world-wide features of ion-distribution in the outer atmosphere. Work reported last year indicated certain fluctuations in ion-density which may be purely local in character, as contrasted with the more universal variations. These fluctuations have been given further detailed attention during the past year—an emphasis which was made possible by the availability of the continuous homogeneous data from the observatories. In particular, methods of separating universal variations from those of purely local character have been investigated in order that the origin of each kind of fluctuation may be determined.

PRINCIPAL INVESTIGATIONS

Origin of ionospheric fluctuations. The solution of this important problem depends primarily upon analysis of data from suitable locations such that the observed variation can be broken down into simple fluctuations arising from individual sources. Solution of the problem is contingent upon availability of continuous data for analysis. Operations of recording apparatus at the magnetic observatories of the Department are fulfilling this need.

Analysis of the F_2 -region of the ionosphere has shown that over the period of a year there are three major changes: (1) a seasonal change, with the maximum of ion-density occurring near midwinter in both northern and southern hemispheres, the time of maximum differing by 6 months between the two

hemispheres; (2) an annual change, having a maximum about January in both hemispheres, the source of which is not understood; and (3) a change with sunspot-number, which appears to go through a complete cycle in phase with the sunspot-cycle. All these are major variations and when combined determine the average ion-density at a particular location. Superimposed on this average are daily and other short-period variations which change in magnitude according to the time of year, latitude, sunspot-number, and character of simultaneous magnetic activity. The extent to which the magnitude and character of daily variations are related at two stations on a particular day must be evaluated in determining the origin of such variations.

Investigations during the past year show that fluctuations of ion-density with magnetic activity are evident at both Huancayo and Watheroo for even very small magnetic activity, as low as index 1 on the scale of 0 to 9 of the *K*-index of geomagnetic disturbance. The nature of the ionospheric disturbance is not the same at both observatories. At Huancayo the average ion-density taken over the day rises steadily as magnetic activity increases, until limited by unusually severe disturbances, when the *F*₂-region simply "blows up" and disappears, as described later in this report. At Watheroo the relation between ionization and geomagnetic activity changes with season. During the summer the ion-density falls steadily with increasing geomagnetic activity. During the winter the ion-density rises, as at Huancayo, until moderate geomagnetic disturbances are observed, and then falls rapidly with increased disturbance in much the same way as in summer. Thus fluctuations from day to day at the two observatories are related in a complicated way through association with geomagnetic activity. During the summer the relationship is inverse for all but the severest geomagnetic disturbances; during the winter, however, the relationship is direct for moderate, and inverse for the more severe geomagnetic disturbances. The pattern at Washington is similar seasonally to that at Watheroo.

The amplitude of diurnal variation changes with season and with sunspot-number at both stations. After correction for difference in latitude, and after removal of these variations, there remains a large irregular fluctuation in ion-density which does not appear common to both stations. The question is whether this is local in character or is caused by rapid change in the solar ionizing radiation as the Earth rotates from noon at Huancayo to noon at Watheroo—in time, about one-half day. To answer this question, automatic multi-frequency recorder no. 3 was constructed and installed at the Experimental Station of the Department at Kensington, Maryland (near Washington, D. C.). This recorder provides data for direct comparison with Huancayo. Since Huancayo and Kensington are on the same meridian, noon occurs nearly simultaneously at both stations; therefore, changes in ionization arising from changes in solar radiation should be common to both stations. Thus, as data become available from this third station, it should be possible to identify more exactly that portion of the change in diurnal variation of ion-density for which the Sun is directly responsible and that portion which is of local origin. The data should also afford valuable collateral evidence to aid in identifying the cause of the annual effect.

The possibility that local variations of ion-density of large magnitude may occur raises some interesting problems. The question may be asked whether such local fluctuations could arise from meteorological influences. Meteorologists heretofore have thought that atmospheric movements were confined entirely to the lower atmosphere, with the outer atmosphere entirely quiescent. The recent work of Martyn and his associates shows that further investigation of this point is desirable to determine whether or not any relation exists between meteorology of the lower and of the outer atmosphere.

E-region investigations. Evidence obtained during radio fade-outs (see annual reports in Year Books Nos. 36–38) has demonstrated that electrical currents flowing at levels between 60 and 100 km are probably responsible for the daily changes in geomagnetism. It

appears that within this region of the atmosphere much of the solar influence is translated into geomagnetic effect. Detailed investigation of this region would therefore be fruitful and is under way.

Four lines of effort seem promising, especially with regard to changes during the day, with latitude, with season, and with variation of solar radiation. These lines are: (1) comparison of continuous observations of *E*-region ion-density at different locations with existing theories to determine the adequacies or deficiencies of the theories; (2) investigation of special conditions during eclipse of the Sun; (3) critical experimental investigation of change of ion-density with height and time of day for comparison with theoretical predictions; and (4) determination of conductivity with respect to height. This program should ultimately lead to an exact quantitative theory for the *E*-region from which conditions at any location may be satisfactorily predicted. Research on the first two lines is under way and plans for the third and fourth are under consideration.

Examination of maximum ion-density at Washington, Watheroo, and Huancayo shows that daily changes are not satisfactorily predicted by existing theory. Though deviations from theoretical values are not more than 20 to 30 per cent, they are in a direction which cannot be explained by the theory in its present form. For instance, the rate of decrease of ion-density in the afternoon is greater than would be expected from theory, using infinite values of recombination-coefficient. Earlier measurements did not direct attention forcefully to these discrepancies because ion-density was measured down only to about one-fourth the maximum value. Measurements of ion-densities with the more modern and complete equipment at the observatories carry down to about 1 per cent of maximum values; these make the discrepancies quite apparent. It is clear, therefore, that further theoretical work must be done to reconcile theory and experiment. This portion of the investigation is along two lines, namely, (1) compilation of experimental data to facilitate theoretical investigation and (2)

study of factors in the theory, hitherto neglected, which must be taken into account to obtain agreement. Observations during solar eclipses are especially useful for determining values to be used in the theory. The rapid changes during eclipses permit more accurate determination of such factors as recombination-coefficient than is possible under ordinary conditions.

Observations were made during the solar eclipse of April 7, 1940, at the Kensington Experimental Station, where the eclipse reached 73 per cent totality. During the early stages of the eclipse maximum ion-density decreased more rapidly than was predicted from normal-day conditions. This would indicate that the Sun is not giving out the ultraviolet ionizing radiation uniformly from every part of its surface. It appears that during the early stages of the eclipse one of the more active portions of the Sun's surface was covered so that the production of ionization was decreased more quickly than would have been expected from a uniformly radiating surface. Observations of both *E*- and *F*₁-regions confirm this view.

Plans were perfected and arrangements were made for similar observations at the Huancayo Magnetic Observatory during the solar eclipse of October 1, 1940. Here the Sun will rise almost totally eclipsed, so that especially valuable information concerning conditions at sunrise is expected. For these observations the standard multifrequency observations are made at about three times normal speed, so that a complete set of observations is available at intervals of about five minutes.

Plans have been made for precise measurements of height-variation of the *E*-layer. This requires a new technique involving the interference of the transmitted wave and the wave reflected from the ionosphere. Success of this method should permit measurements of height-changes of a few meters, an accuracy required because of the small changes in height experienced in the *E*-region.

Ionospheric changes during great magnetic storms. Continuous ionospheric observations through the recent maximum of solar and

geomagnetic activity have made possible delineation of ionospheric changes during the magnetic disturbances associated with this maximum. The great disturbance on Easter Sunday, March 24, 1940, was probably the most violent magnetic storm yet observed. At the beginning of this disturbance at the Huancayo Magnetic Observatory the F_2 -region of the ionosphere rose rapidly in height at a velocity one-third to one-half of the velocity of sound. As the height increased the ion-density decreased. At the end of 30 minutes the ion-density had diminished to less than 20 per cent of its original value and ionization in the F_2 -region could be observed only at great heights, of the order of 1000 km. The event appeared to be a sort of gigantic explosion of the outer atmosphere above levels of 250 to 300 km. As the F_2 -region of the pre-storm epoch was rapidly disappearing upward, a new F_2 -region was formed in place of the old, probably because of the continued incidence of ultraviolet light. This new region formed rapidly and provided information which made possible calculation of the rate of production of ionization in the F_2 -region—a calculation practically independent of any theory of F_2 -region variation. It is as though the Sun were suddenly "turned on" after rising over an un-ionized atmosphere, ionizing it during an interval over which no material change of solar zenith-distance occurred. Ionospheric disturbances of this kind are extremely rare, as are the great geomagnetic disturbances associated with them. One such disturbance occurred on April 16, 1938, and was reported last year (see Year Book No. 38). The general pattern of movement of the ionosphere was the same at Huancayo during both disturbances. This earlier disturbance took place at night at Huancayo, so that the Easter disturbance remains unique in so far as data are available for basic computations of quantity of ionizing radiation.

Study of radio fade-outs. The time and intensity of radio fade-outs, given by ionospheric records, provide investigators of magnetic phenomena with data on fade-outs preceding major magnetic disturbances. From

these the geomagnetician can calculate the velocities of corpuscular streams thought to emanate from active solar areas and thought to be responsible, as these streams envelop the Earth, for magnetic disturbances.

Relation between actual and virtual ionospheric height. Ionospheric records result from successive measurements of height for successive values of ion-density. The curves so formed photographically in the recorder show in effect a graph of ion-density versus "virtual" height. The curves are in terms of virtual rather than actual height because the exploring wave travels at a reduced velocity in the ionized regions. The virtual height, therefore, is always greater than the actual height by an amount which depends upon the density and distribution of ionization through which the wave has passed in reaching the point at which it is turned back. Reduction of virtual to actual height has been one of the most troublesome problems. Generally the equations are so complex that the reduction to actual height could be made practically for only a very few ionospheric records.

To meet this situation, a simple method of determining actual height of ionization has been developed which is readily applicable to most records. Virtual heights of the ionosphere are translated to actual heights by fitting a parabolic maximum of electron-density to observations of variation of virtual height with wave-frequency. The simplest measure of actual height of maximum electron-density is the virtual height at five-sixths of the penetration-frequency. This measure is found to be remarkably reliable for the F -region at night; other indices for determination of height and thickness of the layers can also be applied with equal reliability. During the daytime it is often necessary to correct F_1 -observations for presence of E -region, and F_2 -observations for presence of F_1 -region. A simple technique for this correction has been developed.

Application of the new technique to a large number of records shows that the actual layer-distribution can be successfully represented as a parabolic distribution with ample accu-

racy for most purposes. It appears doubtful whether more detailed and laborious computations yield a very much better result.

The parabolic distribution can be represented easily and exactly by two simple numbers, namely, the maximum ion-density and the semi-thickness of the layer. Thus the representation of each layer is greatly simplified for purposes of mass-analysis of data for the many variables involved.

Maximum usable frequency for long-distance communication. The relation between the maximum usable frequency for long-distance communication and the penetration-frequency of the layer at vertical incidence depends upon whether the Sellmeyer or the Lorentz theory is employed. Analytical expressions for the ratio of these two frequencies on both theories have been obtained taking into account the curvature of the Earth. For a given penetration-frequency at vertical incidence, the maximum usable frequency for long-distance communication is greater for the Lorentz theory than for the Sellmeyer theory by a factor $\sqrt{3/2}$. It has been suggested that this effect would be marked by the fact that the parabolic maximum of electron-density required to fit the variation of virtual height with wave-frequency observed at vertical incidence would depend on whether the Sellmeyer or the Lorentz theory is used. It turns out, however, that this is not the case. Observations so far made of the relation between maximum usable frequency and penetration-frequency favor the Lorentz theory, but are not conclusive.

Scattering of waves from the ionosphere. Waves scattered back to the transmitter from the Earth via the layer would form on an automatic multifrequency record a blurred trace having a sharp lower edge of the following type: Let ABC be the curve of the second multiple reflection at vertical incidence, drawn on a linear frequency-scale. Let O be the point corresponding to zero virtual height and zero frequency. From O draw a tangent to ABC touching it at B . Produce OB indefinitely to D . Then, on the Sellmeyer theory, the lower edge of the scattered trace is given

by the curve ABD . On the Lorentz theory, the portion BD would be slightly curved. An echo of this type is quite common on automatic multifrequency records.

In the above investigations the effect of the Earth's magnetic field has been neglected. Progress has, however, been made with the theory of propagation of waves through a horizontally stratified ionosphere taking into account the Earth's magnetic field. Curves for a series of typical cases of oblique incidence have been plotted.

Polarization of downcoming waves. Determination of the state of polarization of the downcoming waves from the ionosphere forms one of the most rigorous experimental methods of testing the theory of propagation. Theory predicts that at the Huancayo Magnetic Observatory waves reflected from overhead should be plane polarized, and earlier work at Huancayo on the F_2 -region using manual step-by-step methods has shown this to be correct. These experiments were repeated with modern equipment and a rotatable antenna. The results of the original experiments have been confirmed and their general applicability to all regions of the ionosphere has been extended. The theory from which ion-density is computed must now be generally accepted as meeting all the observed facts, the only quantity remaining in doubt being the value of the Lorentz polarization-correction (see report of last year).

RECORDING AND DISCUSSION OF DATA

Recording of data. The use of automatic multifrequency apparatus for continuous recording of ionospheric conditions was continued throughout the year at both the Huancayo and Watheroo magnetic observatories. The success of this program is to be credited largely to the staffs of the observatories, whose careful supervision of the relatively complex apparatus has made possible a practically homogeneous series of records with negligible loss of traces because of mechanical or electrical failures. Continuous records of the third apparatus, at the Kensington Experi-

mental Station, have been obtained from early in April 1940. After one year's operation at Kensington this apparatus will be available for field-work.

Standardization of recording technique—an important factor in simplifying operation—has become possible with the accumulation of experience in the field. As a result, observers can now be trained in procedures for maintenance and calibration before assignment to the observatories.

Tabulation and publication of data. Nine sheets of scalings from the records are prepared monthly at each observatory. On these are tabulated the hourly values of minimum virtual heights and heights of maximum ion-density of the F_1 - and F_2 -regions, penetration-frequencies of the E -, F_1 -, and F_2 -regions, minimum wave-frequency at which reflections occur, and the squares of the F_2 penetration-frequency. Daily means and hourly values of monthly means are computed on each sheet. The mean data for each month are published in the *Journal of Terrestrial Magnetism and Atmospheric Electricity*, and thus made available to investigators at the earliest possible date. Annual averages are published at the end of each year. Tabulations of sporadic E -region ionization at Watheroo have been discontinued, as it has become evident from experience that such investigations will require a more complex analysis than can be given in the time available at the Observatory. Radio fade-outs, which are occurring with diminished frequency as sunspot-activity decreases, are tabulated monthly.

Harmonic analysis of data. Harmonic analysis of the F_2 -region data, for detailed study of variations of ionization, is made at the Department directly from the hourly tabulations compiled at the observatories. For analysis of maximum values of the F_2 -region ionization, a 12-ordinate system is used and harmonic coefficients for the first five harmonics are derived. Harmonic analysis of these data is practically completed through 1939 for both observatories. Harmonic analysis of minimum virtual height at both observatories has been made for 1938 and part of

1939, to permit study of the usefulness of this type of analysis for the height data.

Personnel. The program of ionospheric investigation was maintained by Berkner and Seaton at Washington and Wells at Huancayo, together with Booker as Research Associate at Washington and at Cambridge, England. Aid in computations was given by Niepold and Jones, and Ledig assisted at the Kensington Experimental Station. The staffs at the observatories supervised and maintained the equipment at the observatories.

COOPERATIVE ENDEAVORS

Sixth Conference on Ionospheric Research. The Sixth Annual Conference on Ionospheric Research was held in the library of the Department of Terrestrial Magnetism on April 27, 1940, under the chairmanship of Dr. O. R. Wulf, of the U. S. Weather Bureau. It was attended by forty-one persons, representing the following organizations interested in ionospheric research: Bell Telephone Laboratories; Department of Terrestrial Magnetism, Carnegie Institution of Washington; R. C. A. Communications; Jansky and Bailey; Signal Corps, U. S. Army; Harvard University; Q S T Technical Staff; National Bureau of Standards; U. S. Coast and Geodetic Survey; Naval Research Laboratory; Federal Communications Commission; U. S. Weather Bureau; Gulf Research and Development Company; University of Rochester.

The importance of purely scientific research in terrestrial magnetism was emphasized by discussions at the Conference. Conversely, experience derived from commercial radio communication was shown to have important bearings on scientific knowledge of geomagnetism. As at previous conferences, the greatest interest was evoked by discussions of magnetic storms and their association with marked changes in conditions of transmission. The discussion indicated the development of various widely different lines of research during the past year. Improved methods of evaluating transmission-disturbance, and application of the new range-index K for measuring magnetic activity to problems of com-

munication, were discussed in some detail, as was comparison of work on many other ionospheric and wave-propagation problems.

Papers or lectures were given by members of the Department before a number of scientific and other organizations, including the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics, Philosophical Society of Washington, International Scientific Radio Union, Institute of Radio Engineers, Washington Radio Club, and Section on Physics of the Eighth American Scientific Congress. The Department was represented at the annual conventions of the Institute of Radio Engineers and the American Institute of Electrical Engineers. The Carnegie Institution of Washington was represented on the Executive Committee of the International

Scientific Radio Union, on the Wave-Propagation Committee of the Institute of Radio Engineers, and on the Joint Committee for Ionospheric Research, Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics, by Berkner. Because solution of problems of ionospheric research requires widespread distribution of stations over the Earth to elucidate the detail of world-wide ion-distribution, the Department maintains close cooperation with other organizations doing ionospheric research throughout the world. In many cases it has been possible to assist other organizations in the development of apparatus and in the interpretation of data. Conversely, the information obtained through close cooperation with other organizations has been helpful in the development of problems.

MAGNETISM AND ATOMIC PHYSICS

INTERACTIONS OF THE PRIMARY MATERIAL PARTICLES

The existence of a new type of interaction between material things, namely, the intense short-range forces between the protons and neutrons which form the nuclei of all atoms, has been amply confirmed during the past several years. These nuclear forces are fundamental in the same sense that gravitational and electromagnetic forces are fundamental: all three are universal in Nature; they cannot be derived from one another, but all known forces or interactions between material bodies can be described in terms of them. It is not inconceivable that a connection of some kind exists between these fundamental forces, and indeed experimental evidence has been sought, for example, for effects of nuclear forces on electrons, which are presumed to be simply electric charges with magnetic moment but without associated nonelectrical mass. The fact that the neutron has a magnetic moment and exhibits the same nuclear-force properties as the proton, although it has no electrical charge, also indicates the possibility of ultimately finding a relationship of some kind. To illuminate these funda-

mental questions concerning the nature of magnetism and its role in the intimate structure of matter, experiments which reveal the action of electrical, magnetic, and nuclear forces in various cases of close interaction between primary particles, limited to the simplest cases of a few particles to permit detailed analysis, are being formulated and made.

The measurements on the proton-proton interaction at the Department three years ago have been confirmed and extended by other workers. Further deductions regarding this type of pair-forces can best be made by utilizing protons accelerated through potentials of the order of 5,000,000 volts or even higher. The construction of the Atomic-Physics Observatory and its equipment was not rewarded with the good fortune of immediate attainment of these expected voltages. Considerable time was expended by the staff, especially Hafstad, Meyer, and Heydenburg, on improving the voltage and other operating characteristics of this equipment. Improvement was achieved, the unit being made to operate satisfactorily up to 3,600,000 volts and at times somewhat higher, but it seems clear that the original vacuum-

tube installed at the end of 1938 must be taken down and fitted with new electrodes, or that other internal modifications must be made, before further improvement is to be realized. Failure, by sparking, also occurs down the porcelain columns at peak-voltage, and some changes in the support-structure made this year point in the direction of further improvements. An effort is made, however, to confine these tests and changes to limited time-intervals, permitting the use of the equipment for nuclear-physics measurements and the production of radioactive materials during the rest of the time.

SPECIFIC PROJECTS

Attacks were made on five different problems concerned with the forces acting between the primary particles.

Salant and Ramsey concluded an extensive series of observations begun last year on the scattering of very fast neutrons by collisions with protons (hydrogen). They utilized the group of 14- to 16-mev neutrons emitted by lithium under deuteron bombardment, using as a detector an endothermic nuclear reaction in copper which does not respond to neutrons of lower energy. Their final value for this scattering cross-section agrees rather closely with the value predicted by a theory which is not elaborated to include the deuteron quadrupole moment and other recent features, thus setting another limit on the extent to which these features may preponderate.

Van Allen and Ramsey attempted to measure the angular distribution of the scattering of fast (15-mev) neutrons by protons, using a triple-coincidence arrangement of proportional counters to reduce the background of neutron-recoils of lower energy. This attempt has not yet been successful, but the observations have indicated that the measurement may be feasible if certain modifications are made. If this angular distribution can be obtained, it will be valuable as a measure of the energy-region in which unsymmetrical interactions of higher order become important in scattering. This region has not yet been determined for either the proton-proton or the proton-neutron interaction, and knowl-

edge of these higher-order interactions seems essential to a further development of our understanding of the nuclear forces. A current question, for example, is whether the nuclear forces arise from the interaction of mesons (heavy electrons) with the massive nuclear particles.

An experiment in connection with the difference between the interaction of a proton with a group of nuclear particles and that of a neutron with the same group was made by Ramsey and Heydenburg. In addition to the difference arising primarily from the charge on the proton, other differences exist, even though the masses of these two particles are nearly alike and the measured proton-proton and proton-neutron pair-interactions are practically equal when correction is made for the electrostatic forces. For example, the magnetic moment of the proton is more than twice that of the neutron. The convenient analytical approach of treating the interaction of an added particle as that of a single unit interacting with the averaged effect of the group, used in treating the outer parts of an atom, cannot be relied upon for the nucleus, since the particles are so close together and each interacts with every other one simultaneously. This is a many-body problem which in general is insoluble, and it is accordingly important to learn how nearly the single-particle picture fits experimental behavior in various typical cases. A resonance-effect in the collision cross-section for neutrons in helium was observed elsewhere two years ago, the collision-area being increased by a factor of about 5 for neutrons in a narrow band of velocities in the region around 1 mev. It was of interest to see whether a related resonance exists for proton-collisions in helium, at a somewhat higher voltage (velocity) to compensate for the electrostatic repulsion experienced by the proton approaching the helium nucleus. The experimental observations carried from 1.0 to 3.1 mev showed a proton-resonance, but by comparison it was very broad and shallow, extending roughly from 1.5 to 2.5 mev, with an increase of collision-area of at most 50 per cent for certain angles. Theoretical examination shows this difference

to be understandable because of centrifugal forces and the charge on the proton. Various details of this scattering were examined with particular reference to higher orders of waves (interactions with different angular momenta).

The target-area for collisions between neutrons and protons is large for neutrons which have been slowed down to the low velocity corresponding to ordinary thermal agitation, and decreases rapidly as the relative velocity is increased. This fact has been explained as the resonance-effect of "a virtual level of the deuteron," or a quasi-stable state of association of a proton and a neutron. This simple theory predicts a definite way in which the collision-area should change with velocity, being adjusted at the lowest and highest velocities to agree with experiment. Rough measurements at the Department in 1936 gave approximate agreement of the observed collision-area for neutrons of intermediate speed (0.6 mev) with the predicted intermediate value. This agreement was important because the experimentally determined proton-proton interaction had just been found to be very nearly the same as the neutron-proton interaction corresponding to the theory. Measurements last year in another laboratory, however, gave a much smaller value for the collision-area of medium-speed neutrons, throwing the whole question of the neutron-proton interaction and its equality with the proton-proton reaction into serious doubt. The problem was therefore re-examined by Salant and Tuve by means of an entirely new series of measurements. These measurements were much more accurate than the determinations of 1936 and again agreed satisfactorily with the predictions of the simple theory, although a slight deviation is not excluded. In addition, it was shown that the observations which had thrown doubt on the agreement were in error because a method of measurement was employed which responded to gamma rays as well as neutrons, and rather intense gamma rays accompanied the neutrons used.

A question which is basic in all considerations regarding atomic nuclei is that of the

role of the lighter particles, electrons, or mesons (heavy electrons) inside the nucleus. To what extent may a proton be considered as a combination of a neutron and a positive electron? Early attempts at understanding the binding forces which hold protons and neutrons together as a nucleus pictured an exchange of the positive charge between two neutrons, effectively combining proton and neutron. The theory failed to predict correctly various facts, such as the half-life of beta-ray emitting nuclei; and the demonstration of a proton-proton attraction led to the current theories which relate nuclear forces to the exchange of mesons between nuclear particles. These theories are in an unsatisfactory state, and further experimental information is needed. Mesons are observed in cosmic-ray studies, but are not under control and are not available in the numbers needed for studies of their nuclear interactions. Electrons have such a small mass that the electrostatic effects in or near nuclei are overwhelmingly large, even for electrons having energies of 5 or 10 mev. An indirect attack on the behavior of the electrically charged entities in nuclei seems possible, however, by careful studies of the effects of high-energy electromagnetic radiation (gamma rays) on nuclei. Van Allen has made experiments on the photo-disintegration of the deuteron into a proton and a neutron, using the 6-mev gamma rays emitted by fluorine and the 17-mev gamma rays from lithium, when these elements are bombarded by protons. An absolute calibration of the numbers of gamma-ray quanta emitted in these reactions is in progress.

URANIUM FISSION

The possibility that "atomic power" might ultimately become available in the form of heat evolved from a chain-reaction in uranium, hypothetically conceivable because the splitting or "fission" of a uranium nucleus is caused by the capture of a neutron and the fission-process is accompanied by the emission of free neutrons, was discussed in last year's report. Measurements in this connection have

been made in many laboratories, and the question is still open. At the Department special attention has been paid to the target-areas for fission-production by fast neutrons, and other relevant measurements. An important contribution to the subject was made by Abelson. An unknown substance having a half-life of 2.3 days was found during 1939 by Segre in Berkeley. It was not a fission-product (non-recoiling), yet the target-area for its production was almost as large as for fission. During the year it was shown elsewhere that the isotope U^{235} is responsible for the fissions produced by slow neutrons, and a chain-reaction might well be expected if a way could be found for separating this isotope in large amounts. However, if the 2.3-day substance arose also from U^{235} , enough neutrons might be consumed by this nonfission process to prevent the propagation of a chain. Efforts by Abelson and Hafstad to identify this substance by experiments using the Department's equipment were not successful. During a recent visit by Abelson to Berkeley, however, he and McMillan, of the University of California, with the higher neutron-intensities available there, succeeded in demonstrating that the 2.3-day process arises from element 93²³⁹. This element originates from the isotope U^{238} , and hence the considerations regarding a possible chain-process using U^{235} are clarified.

MISCELLANEOUS

A variety of more or less incidental observations and studies were made during the year. A search for stable H^3 showed that it was not present in amounts as great as 10^{-12} of the deuteron-beam from the high-voltage tube, indicating that it does not exist as a stable isotope, in agreement with the discovery of radioactive H^3 .

Considerable thought and discussion again was given to the development of designs for an "electron whirlpool," a device having as its objective the acceleration of electrons to extremely high velocities (in excess of 10 mev) by utilizing the electric field of a changing magnetic field. Numerous measurements

were made on the yields of various nuclear reactions at different voltages, as required for current experiments.

A carefully developed comparison of the methods of statistical analysis used in physics and geophysics with those used in economics and the social sciences was made by Hafstad. The methods are mathematically equivalent in a broad region of their application, but special fields are covered by each type of analysis which are not amenable to treatment by the other. Neither group of investigators seems fully to have realized this fact previously, and Hafstad's treatment is likely to be of considerable future importance.

The emergency growing out of violent changes in world affairs has led to expenditures of time and effort in connection with national defense which are not described in this report.

THEORETICAL-PHYSICS CONFERENCE

"The interior of the Earth" was the subject of three days of intensive discussion at the Sixth Annual Conference on Theoretical Physics held in Washington March 21-23, 1940, under the joint auspices of the George Washington University and the Institution. A group of 14 investigators in geophysics and in theoretical physics from various universities in the United States joined a similar number of Washington investigators for technical examination of some of the outstanding problems concerning matter in great bulk and under large pressures and temperatures, as found inside the Earth. The chief aim of the discussions was to formulate these problems more clearly for future joint efforts.

The first meeting was devoted to the pressure-volume relation at high pressures and associated questions concerning the probable composition and physical state of the Earth's deep interior. For pressures higher than about 10^8 atmospheres the pressure-volume relation can be estimated statistically, and all materials must behave in a similar way. At these pressures the outer electronic shells of the atoms are crushed, and in this region the pressure increases with the 5/3-power of the density.

However, the pressure at the center of the Earth reaches a value of only about 3×10^6 atmospheres. Some calculations have been made for the intermediate region down to about 10^7 atmospheres, and, interpolating between these calculations and the experimental data at 20,000 to 50,000 atmospheres, one finds agreement with the densities and compressibilities which geophysicists have deduced for iron in the core of the Earth. As one immediate result of these discussions, further calculations along similar lines are now in progress for the region below 1,000,000 atmospheres.

The melting point of iron under a pressure of 3×10^6 atmospheres was examined, and the calculations indicate a value of $10,000^\circ$ K, which is somewhat higher than previous estimates. The evidence from seismology and earth-tides which indicates that the deep interior of the Earth is in a fluid rather than a solid state was discussed, together with various considerations bearing on the composition and probable stratification of the interior.

Related material of special interest was presented by Goranson, who discussed new measurements of compressibility extending to a pressure above 200,000 atmospheres.

The main topic of the discussions on the second day was the origin and maintenance of the great magnetic field of the Earth. Beginning with a description of the magnetic moment and its representation by a minimum number of internal dipoles, the secular variation was discussed and various data and calculations were presented with regard to the electrical conductivity of the Earth at different depths, as inferred from the diurnal and magnetic-storm variations. Theories of the Earth's magnetic field were examined at some length, including recent ideas according to which the magnetic effects may be due to large thermoelectric currents maintained by mass-convection currents in the fluid core. Calculations which throw some doubt on this theory were put forward by members of the Conference; these calculations were subsequently published in the *Physical Review*.

The dynamo-theory in relation to the Earth's interior, and the possibility of a ferromagnetic core were discussed. The Conference left the Earth's magnetic field as great an enigma as before, but evidently resulted in an appreciation of its challenge and a stimulus to further attack.

The remainder of the discussions were devoted to radioactivity in the Earth and to problems of viscosity.

This Conference had the following objectives: (a) to formulate the problems and data of geophysics which may be of interest to workers in theoretical physics; and (b) to put at the service of workers in geophysics the growing theoretical knowledge concerning the behavior of matter under unusual conditions, especially at very high pressures. That this meeting provided an immediate basis for further cooperative work has been demonstrated, as extended calculations on several questions have already been undertaken by several theoretical physicists.

THE CYCLOTRON PROGRAM

An expansion of the Department's activities in nuclear physics to embrace an enlarged program of fundamental work in biology and chemistry, utilizing the artificially radioactive isotopes of ordinary elements as tracers for following various reactions, was undertaken. This program will center around a large cyclotron, essentially a duplicate of the 60-inch cyclotron installed last year at Berkeley, and will involve cooperation with various members and groups of the Institution's staff working in chemistry and biology, and with a number of other research organizations in the Washington area, such as the National Cancer Institute, the Department of Agriculture and other federal agencies, one or more of the local universities, and the Johns Hopkins University in Baltimore. In addition to the work with radioactive tracers, the cyclotron will provide for still further extension of the Department's studies of atomic nuclei and the primary particles of matter.

For putting this large project into operation, the first necessities were the selection

of personnel, the design and construction of a highly specialized laboratory building, and the construction and installation of the cyclotron itself. Roberts, Abelson, and Green were selected to work with Tuve on this project, and Cowie was assigned here from the staff of the National Cancer Institute. The new laboratory is well under way, and many of the large parts of the cyclotron are completed or under contract for early delivery. It is expected that the remaining details of small parts, wiring, installation of controls, and assembly may be completed by July 1941.

An important part of the initiation of this project, which contemplates the joint activity and initiative of investigators in widely separated fields for the broadly defined purpose of fundamental research, aside from therapeutic questions, is the development of a sound basis for guiding the work with regard both to technical and to administrative or liaison questions. Actual experience in such cooperative work is the only reasonable basis for guiding the project as a whole, and arrangements were made to supplement our previous experience by pushing forward a group of specific problems, using the existing high-voltage equipment, concurrently with the construction of the cyclotron. These efforts already have been valuable in a number of ways, even including modification of the building plans to incorporate features peculiar to the requirements of simultaneous tracer-work with different radioactive elements, recognized only as a result of operating two such projects simultaneously. The gaining of experience on a small scale before attempting to utilize the great output from a 60-inch cyclotron has been valuable to the cooperating agencies as well.

SHIELDING

The powerful radiations from a cyclotron are dangerous for personnel of the laboratory unless arrangements for adequate shielding are provided. In addition, much smaller amounts of stray radiation or activity in the rooms of the laboratory will give a large and fluctuating background on the instruments used for following radioactive tracer-samples. The

shielding arrangements necessary for a specified reduction of intensity were not known, but calculations made on the basis of measurements using the Department's high-voltage equipment, checked by rough measurements on existing cyclotron-installations, indicated the necessity for completely enclosing the 60-inch cyclotron, and providing an 8-foot cover of moist earth overhead to prevent back-scattered radiation from the air above the laboratory. Numerous technical features were incorporated in the building to reduce the importance of stray radiations, including a separate instrument-room, shielded over all by an additional 3 feet of earth, for measurements at high sensitivity. The shielding for personnel was based on hospital experience with X-rays, but an added safety-factor of 10 was used because of the still unknown risks of radiation-exposure. Study of the shielding question showed that, although geneticists emphasize the cumulative hereditary effect of radiation-exposure, no genetic experiments using other than massive single doses of radiation have been performed, even with *Drosophila*. Arrangements were accordingly made for a preliminary test of the genetic effects of continuous radiation-exposure (20 roentgens per day) over six or seven generations of *Drosophila*, the experiments being made jointly by the National Cancer Institute and Dr. Demerec of the Institution's Department of Genetics. Cowie stimulated this investigation and also arranged for the Cancer Institute to undertake a survey of the actual exposure to radiation (X-rays and gamma rays) of the personnel in various near-by hospitals and clinics. About half of these groups exceeded the customary tolerance-dosage of 0.1 roentgen per day. This survey is being extended to all parts of the United States.

COOPERATION IN BIOLOGY AND CHEMISTRY

Photosynthesis. Cooperative experiments over several months were made at the Department with the Institution's Division of Plant Biology, using radioactive carbon (C^{14}) for studies of the various ways in which plants

take up carbon dioxide for use in photosynthesis. A plant has a reservoir-mechanism for carbon dioxide taken in from the surrounding air. The absorption of CO₂ into living sunflower leaves by solution in the water of the sap, by reaction with insoluble carbonates, and by reaction with the soluble buffer-substances were processes found to be in operation. In addition, CO₂ reacts to form a non-carbonate derivative of which little is yet known. It has been found that the active absorption of CO₂ is not a necessary part of the initial photochemical reaction, since CO₂ absorbed before illumination can be used for the process of photosynthesis. Whether the carbon newly assimilated in photosynthesis is lost by respiration more rapidly than the carbon from other organic compounds already contained in the leaf has not been determined, but it was shown that this loss due to respiration is rapid.

Arsenic. Another project in this initial program of cooperation in biology and chemistry was the study of the distribution of radioactive arsenic in animal tissues in co-operation with Dr. Ernst A. H. Friedheim, of the University of Geneva. Friedheim, Abelson, and Cowie used radioactive arsenic for the synthesis of a pair of arsonic acids, one of high chemotherapeutical activity (arsanilic acid), and the other of no chemotherapeutical activity (p-arsenobenzoic acid). The distribution of the arsenic of these compounds in various organs of rats, guinea pigs, and rabbits was studied *in vitro* and *in vivo*, the arsenic concentration being determined quantitatively by measurements of radioactivity. Both compounds had similar distribution in animal organs with the exception of the blood. Both showed a definite accumulation of arsenic in the kidney, liver, and skin, as compared with the blood. The concentration in the brain, however, was only a fraction of that in the blood. It was also found that the red blood cells of the rat concentrated the arsenic of the chemotherapeutic arsanilic acid *in vivo* and to a lesser extent *in vitro*, whereas the arsenic of the inactive p-arsenobenzoic acid was not concentrated in these cells. This finding will be

highly significant if it proves to be generally true of chemotherapeutic compounds. The concentration of arsanilic acid in the blood was determined as a function of time and mode of administration.

Placental permeability. Drs. Louis B. Flexner and H. A. Pohl, of the Department of Anatomy, Johns Hopkins University, were assisted in an investigation using radioactive sodium (Na²⁴) to measure the transfer of sodium across the placenta in several groups of animals. Each group of animals studied had a different placental structure. The experiments with the cat have shown several interesting results. The fetus comes to within 10 per cent of a limiting equilibrium-value with respect to sodium ions in the maternal plasma after 16 hours, in striking contrast with the extracellular fluid of the mother, which comes to the same equilibrium in about 4 minutes. The rate of transfer to the placenta (per unit-weight of placenta) has been shown to be very low in the earlier stages of pregnancy (15 to 20 days), but increases linearly to 60 times this value at 57 days. A decrease to term is then observed in this rate. The rate of transfer to the fetus, however, is high in these earlier stages and falls off with duration of pregnancy. This may be explained on the basis of the ratio of the size of the placenta to that of the fetus, this ratio decreasing as the fetus develops.

Neutron-irradiation. Dr. Demerec, of the Institution's Department of Genetics, has in the past investigated the dosage-effect relationship of 1000 to 5000 roentgens of X-rays on *Drosophila*, both by genetic and by cytological methods. To determine the comparative effects with neutron-irradiation, *Drosophila* of the same strain used for the X-ray investigations were given 2000 "roentgens" of neutron exposure and sent to Demerec for analysis. One interesting point being examined is whether the intense local ionization due to neutron-recoils may produce a higher frequency of multiple chromosomal breaks than with X-rays. Further work will be undertaken with the higher neutron-yields of the new cyclotron.

Neutron-bombardments of tissue-cultures

were made for Dr. George O. Gey, of the Johns Hopkins University. Measurements made on the radiation received by his control tissue-cultures revealed that these controls accidentally received from 40 to 100 times the residual irradiation normally arising from radioactivity of surroundings, owing to the proximity of radium sources. One of these control-cultures of normal rat tissue underwent a spontaneous transformation and acquired tumor-producing characteristics, proved by injection and growth. This malignant transformation is of special interest in connection with the question of the effects of long-continued irradiation.

Plant-nutrition. Radioactive sodium and phosphorus samples were supplied to Dr. Keith Brewer, of the U. S. Department of Agriculture, for certain studies in plant-nutrition. He measured the absorption and elimination of these elements by plant-roots in relation to temperature, pH, antagonistic ions, and other factors.

Miscellaneous. Each of the above cooperative projects required a considerable amount of preliminary effort and joint endeavor of physicist and biologist before the actual measurements could be made on a selected problem. Measuring instruments and techniques suitable for use on a variety of different problems and capable of yielding satisfactorily accurate results without difficulties of maintenance in the cooperating laboratories had to be devised and tested. Suitable instruments are not commercially available, and arrangements were made for having them constructed to order. Each new group which joins this program will require such instruments. A special technique adapted to measuring the radioactivity of liquid samples, involving the solution of various unexpected difficulties before accurate measurements could be assured, was developed as a necessary preliminary to the work with radioactive carbon. This work also required a careful determination of the decay-period of C¹¹, since measurements of the activity after periods exceeding 2 hours, or six times the half-life, were required as ratios to the initial activity with an accuracy of 1 or 2 per cent.

With the help of Dr. U. Fano, of the Washington Biophysical Institute, attention was given to various theoretical aspects of biophysical problems, in particular with regard to the so-called "hit-theory" of the biological action of radiation, as well as other mathematical aspects of radiation and genetic problems.

PUBLICATIONS

Problems relating to the above investigations are noted in the bibliography at the end of this report.

Demonstrations of uranium fission, radioactive tracers, and artificial radioactivity were conducted in connection with the annual exhibition of the Institution and with various lectures relating to research in nuclear physics. Many addresses were prepared for meetings of scientific societies and for physics colloquia, including those at the California Institute of Technology, Catholic University of America, Cornell University, George Washington University, Johns Hopkins University, University of Illinois, and University of California.

COOPERATION IN NUCLEAR PHYSICS AT THE UNIVERSITY OF WISCONSIN

Professor G. Breit, of the University of Wisconsin, continued as Research Associate and consultant. The results of investigations by him and his associates are here summarized.

Proton-proton scattering. The *p*-wave effects on Bethe's neutral form of meson theory have been calculated in collaboration with Kittel and Thaxton for proton-energies of 2.0, 2.4, and 3.0 mev. The range of nuclear force corresponding to a meson mass of 180 electron-masses gives effects of the order of a few per cent of the total scattering. These effects do not vanish at the scattering angle of 45°. Comparison of the theoretical and experimental angular distributions indicates at present that *p*-wave effects predicted by the above meson theory with a mass of 180 m are too large, since they give too much small-angle scattering.

The theoretical phase-shift curves and ex-

pected scattering due to the *s*-wave anomaly have been calculated by Hoisington and Thaxton. The Gauss error well and the square well have been found to give similar extrapolations up to 10 mev.

Neutron-proton scattering. Expansions for the computation of *s*-wave scattering for square wells have been arranged in a form convenient for numerical substitution so as to facilitate such calculations by experimentalists. Effects on *p*-wave scattering have been estimated using Bethe's neutral form of meson theory. Effects of the order of 50 per cent in the angular distribution may be expected for 16-mev neutrons. A possibility of a test of this theory is thus indicated by experiments on the scattering of high-energy neutrons.

Metastability of hydrogen and helium levels of atoms in interstellar space. In collaboration with Professor E. Teller, of the George Washington University, it has been found that the mean life of the $2s$ -state of hydrogen in the absence of collisions is primarily determined by the simultaneous emission of two photons. For this reason the mean life is about $1/7$ sec. It is expected that the mean life of $1s\ 2s\ ^3S$ of He I is of the same order of magnitude and that it is much shorter than that of $1s\ 2s\ ^3S$ of He I. The non-adiabatic collisions with electrons are more important than the static effects at small electron densities, leading to a transition-probability of $1/600$ sec $^{-1}$ for an electron-temperature of $10,000^{\circ}$ C and an electron-density of 30 cm $^{-3}$. The effect of static electric fields has been determined in more detail than previously. Radiations due to quadrupole and magnetic dipole effects have been considered qualitatively for $1s\ 2s\ ^3S$

of helium and quantitatively for $2s$ of hydrogen. Experimental evidence supporting the theory for helium has been found by Wilson, of Mount Wilson Observatory. According to his observations it is probable that the life of $1s\ 2s\ ^1S$ of He I is limited by double photon-emission.

Interpretation of resonances in nuclear reactions. Mathematical difficulties make it impossible to solve the collision-problems of nuclear reactions accurately. The approximate methods used, heretofore, have errors which are difficult to estimate. For this reason new methods have been introduced which give practically exact solutions in special cases designed to represent nuclear reactions schematically. Application of these methods indicates the importance of states of excitation of the residual nucleus in the description of reactions. The way in which potential-barriers affect the reaction-probability has been determined in some typical cases.

Relativistic corrections in proton-proton scattering. These have been computed by L. E. Hoisington. Small but eventually detectable effects on the range of force have been found.

Shot-effect calculations. Calculations of shot-effect with a square-law detector have been made.

Fine structure of nuclear levels. The fine structure of He 5 has been estimated in connection with observations by Stephens and Staub on neutron-scattering in He. A larger theoretical structure has been found on the one-body picture of scattering than by Dancoff. His arguments against the explanation in terms of spin-orbit forces do not appear to be conclusive.

FIELD-WORK AND REDUCTIONS

LAND MAGNETIC SURVEY

The results of magnetic observations on land during 1927-1939 were revised by Wallis and Vestine, and preparation of manuscript for publication was begun. Summaries of magnetic data for Africa, Australia, and South America, including determinations of

latitude and longitude, were furnished a number of interested government and private organizations.

The Department has cooperated through the loan of field-instruments to the Cape Town, Cheltenham, Government of South

Australia, and Apia observatories, and to the British East African Meteorological Service, the Aerial, Geological, and Geophysical Survey of Northern Australia, and the U. S. Antarctic Service. Constants and corrections on field-instruments were maintained in co-operation with the U. S. Coast and Geodetic Survey.

Increased attention has been directed to the use of local detailed magnetic surveys in obtaining geological information not readily forthcoming in other ways. A total of 745 stations were occupied with vertical-force variometers by Green in the environs of the volcano Santa María in Guatemala, on an expedition headed by Zies, of the Geophysical Laboratory. Most of these stations were intermediary in spacing between those obtained by McNish in 1939 and serve to assist in averaging out the apparently marked influences of surface rocks from the larger main systematic magnetic changes associated with the volcano. The distribution and number of stations are probably as yet inadequate for careful inferences respecting the internal structural features of the volcano, in conjunction with other geophysical data, but the results will be used in a preliminary study. Green also reoccupied two permanent repeat-stations in Guatemala.

Johnson effected improvements in the design of a new electromagnetic field-magnetometer. Its construction is being postponed pending completion of the Fleming coil-magnetometer.

Grave concern is being occasioned by the present lack of magnetic observations over the oceans, which comprise the major part of the Earth's surface-area. Investigations are under way to determine the utility of continental observations in computing a rough continuation across the oceans of the field as observed on land, as well as the number,

accuracy, and type of observations required on land. This project can yield at best but makeshift results, even though theoretically an accurate knowledge of the field-distribution over a single continent would suffice to determine the field at all points elsewhere on the Earth's surface. In problems of this kind a large number of observations of moderate accuracy would be more useful than a small number of observations of great accuracy, because the rate of change of the field with distance along the Earth's surface should be well defined. The problem of adjusting observations in conformity with the requirements of potential-theory is also under consideration in connection with improvements in techniques of constructing magnetic charts.

FIELD-OPERATIONS AND COOPERATIVE SURVEYS

Secular-variation data in Africa were obtained through control-observations at the Cape Town Magnetic Observatory and through observations in Kenya Colony by the British East African Meteorological Service.

In Australia control-observations supplied secular-variation information at the Watheroo Magnetic Observatory and some work was done in Northern Australia in cooperation with the Aerial, Geological, and Geophysical Survey of Northern Australia.

In North America international magnetic standards of the Department were continued in cooperation with the U. S. Coast and Geodetic Survey at the Cheltenham Magnetic Observatory, where CIW sine-galvanometer 1 and CIW Schulze earth-inductor 48 are the standards for horizontal intensity and inclination.

In connection with the Guatemalan Volcanological Expedition of 1939 for the investigation of the volcano Santa María, two secular-variation stations were reoccupied, namely, Guatemala City and Quezaltenango; besides these, in a total of 743 stations occupied for the study of magnetic anomalies in 404 km along 11 traverses, 7 were repeat-stations with results for only one or two of the magnetic elements.

OBSERVATORY-WORK

Johnston continued in charge of the Section of Observatory-Work. The magnetic reductions and compilations were maintained with the assistance of Scott and Miss Balsam.

McNish continued the study of magnetic data from our observatories. Wait and Torreson completed the compilation of meteorological observations for both observatories over the

11-year period from 1924 to 1934. The members of staff in residence at the observatories are mentioned in their respective reports.

At Watheroo and Huancayo observatories continuous records were obtained of the three magnetic elements, of atmospheric potential-gradient, of positive and negative conductivity of the atmosphere, of earth-currents, of heights of the ionosphere using both multi- and fixed-frequency, and of the meteorological elements, as well as daily spectrohelioscopic observations during the periods assigned by the International Astronomical Union. At the Huancayo Observatory there were also obtained continuous records with a three-component seismograph and a precision cosmic-ray meter.

Half-daily character-figures were transmitted weekly from both observatories, thus continuing the dissemination through *Science Service* of weekly reports of the American magnetic character-figure, C_A .

Beginning April 1, 1940, both observatories began reporting magnetic activity on the more detailed basis of the 3-hour-range index K (see pp. 63-64), to give further assistance in researches in terrestrial magnetism and radio. The K -indices range from 0 for very quiet to 9 for extremely disturbed conditions and are sent by radio or cable to Washington weekly. Similar reports are prepared by the observatories of the U. S. Coast and Geodetic Survey at Cheltenham, Honolulu, San Juan, Sitka, and Tucson. At the Department in Washington the indices from each observatory are normalized to represent world-wide conditions and a mean index K_A is derived for each 3-hour period. Individual and mean indices are published weekly by *Science Service*.

The magnetic and atmospheric-electric programs of the Department were assisted by various magnetic observatories. Our international magnetic standards were maintained at the Cheltenham Magnetic Observatory, and the program in atmospheric electricity and earth-currents was continued at Tucson Magnetic Observatory; both of these observatories are operated by the U. S. Coast and Geodetic Survey. At the Apia Observatory in

Western Samoa, under the auspices of the Department of Scientific and Industrial Research of New Zealand, the work in atmospheric electricity was maintained with the cooperation of the Department of Terrestrial Magnetism.

OPERATIONS AT OBSERVATORIES

The operations at the observatories of the Department and at observatories or organizations with which the Department cooperated are summarized below.

Watheroo Magnetic Observatory, Watheroo, Western Australia. The Watheroo Magnetic Observatory is situated in latitude $30^{\circ} 19' 1$ south and longitude $115^{\circ} 52' 6$ east of Greenwich, 244 meters (800 feet) above sea-level.

The Eschenhagen magnetograph was in continuous operation, with but a small percentage of lost trace caused by occasional failure of the driving clock. Monthly scale-value determinations of the horizontal-intensity variometer were made as in previous years, using the magnetic deflection-method; in the case of the vertical-intensity balance, scale-value determinations, using the electrical method, were made daily. The monthly mean scale-values for both the horizontal and vertical components are given in table 1.

TABLE I
SCALE-VALUES OF MAGNETOGRAPHS, WATHEROO
MAGNETIC OBSERVATORY, 1939

MONTH	SCALE-VALUES IN γ/MM			
	ESCHENHAGEN		LA COUR	
	<i>H</i> (reduced to base-line)	<i>Z</i> (means of daily values)	<i>H</i>	<i>Z</i>
January	2.36	3.27	4.55	2.77
February	2.36	3.29	4.54	2.58
March.....	2.37	3.30	4.48	2.37
April.....	2.38	3.32	4.59	2.64
May.....	2.37	3.35	4.44	2.85
June.....	2.36	3.35	4.50	3.04
July.....	2.41	3.41	4.51	3.44
August.....	2.34	3.44	4.47	3.44
September...	2.34	3.44	4.59	3.06
October.....	2.38	3.45	4.55	3.12
November...	2.36	3.46	4.55	3.08
December....	2.37	3.46	4.57	3.08

The la Cour rapid-run magnetograph was also in continuous operation. Scale-value determinations by the electrical method were made monthly as in previous years. The resulting values are included in table 1.

The preliminary mean values of the magnetic elements for all days of 1939, as deduced from the Eschenhagen magnetograms, referring the elements to the north-seeking end of the needle and reckoning east declination and north inclination as positive, are: declination, $-3^{\circ} 21'.0$; horizontal intensity, 0.24687 CGS unit; vertical intensity, -0.51517 CGS unit; and inclination, $-64^{\circ} 23'.7$. These results indicate annual changes as follows: declination, $+5'.3$; horizontal intensity, $+5$ gammas; vertical intensity, -28 gammas; and inclination $-0'.4$.

The method of assigning magnetic character was revised in January 1940, after which time the reports were based on 3-hourly evaluations of "K-indices," these giving a measure of the proportional deviation from normal quiet conditions. Intercomparisons between the Observatory standard magnetic instruments and CIW magnetometer-inductor 18, at present on loan to the Commonwealth Geophysical Survey, were made during February 1940.

Earth-potentials, over a system of electrodes as described in previous reports, were recorded throughout the year, and the equipment has yielded consistent results. Periodic tests of line-insulation and electrode-resistance were made as before.

The atmospheric-electric program, involving the continuous recording of air-potentials and positive and negative air-conductivities, was fully maintained, although weather-conditions during the calendar year 1939 were unusually adverse to this branch of the Observatory's activities. The total rainfall for the year was the highest since records have been obtained, that is, for 22 years; the monthly totals and the number of days on which rain fell, together with the monthly average falls for 22 years, are shown in table 2.

In consequence, the number of complete days usable in the atmospheric-electric records was considerably less than in 1938. As usual, on a certain number of days during the summer the records were vitiated by the presence of smoke from bush-fires. Reduction-factor observations, for correcting the values of potential-gradient as recorded by the standard instrument to volts per meter over a plane surface, were made on three occasions, the number being restricted because of the difficulty of obtaining suitable meteorological

conditions; usually these determinations are made quarterly. The preliminary values of the atmospheric-electric elements are shown in table 3.

The automatic multifrequency ionospheric recording apparatus functioned practically continuously throughout the year, the only breaks being during brief intervals for maintenance, overhaul, and minor repairs. The regular manual control and maintenance were performed and the scaling and reduction of the records were maintained practically current. Certain changes in scaling, with a view to obtaining additional information

TABLE 2

RAINFALL IN INCHES AT THE WATHEROO MAGNETIC OBSERVATORY DURING 1939

Month	Monthly total	No. days	Av. monthly total, 22 years
January.....	0.81	2	0.35
February.....	4.32	4	0.56
March.....	0.02	1	1.09
April.....	0.42	3	0.92
May.....	2.95	12	2.18
June.....	5.12	15	3.44
July.....	5.05	18	3.01
August.....	3.14	16	2.30
September.....	0.21	4	1.26
October.....	1.91	9	0.83
November.....	0.40	7	0.32
December.....	0.02	2	0.36
Total.....	24.37	93	16.61

from the records, were made during the year in accordance with instructions. Quarterly reports on ionospheric conditions, accompanied by summaries of data and graphs, were transmitted to Washington for publication in the *Journal of Terrestrial Magnetism and Atmospheric Electricity*. Preliminary mean hourly values of ionospheric data for 1939 are shown in table 4.

During the first two months of the report-year communication schedules were maintained with amateur radio stations in Philadelphia and Washington; on the outbreak of the European war, however, instructions were received from the Postmaster-General's Department at Melbourne that all transmitting equipment must be dismantled and rendered inoperative. After further inquiry, the continuation of transmission of the ionosphere-recorder pulse was allowed; but the radio transmission of scientific data from the

TABLE 3

PRELIMINARY MONTHLY MEAN VALUES OF ATMOSPHERIC-ELECTRIC ELEMENTS,
WATHEROO MAGNETIC OBSERVATORY, 1939

MONTH	No. SELECTED DAYS	POTENTIAL-GRADIENT		AIR-CONDUCTIVITY, UNIT 10^{-4} ESU			
		Reduction- factor	Value (v/m)	λ_+	λ_-	$(\lambda_+ + \lambda_-)$	(λ_+ / λ_-)
January.....	11	....	101.1	1.42	1.30	2.76	1.09
February.....	7	....	88.5	1.73	1.68	3.41	1.03
March.....	5	....	83.6	1.76	1.71	3.47	1.03
April.....	11	1.19	91.9	1.97	1.68	3.65	1.17
May.....	10	....	74.4	2.34	2.05	4.39	1.14
June.....	14	....	79.4	2.49	2.21	4.70	1.13
July.....	15	....	85.6	2.33	2.02	4.35	1.15
August.....	14	1.14	92.2	2.16	1.84	4.00	1.17
September.....	16	....	99.2	1.84	1.57	3.41	1.17
October.....	12	1.19	92.2	1.83	1.58	3.41	1.16
November.....	11	....	84.1	1.72	1.65	3.37	1.04
December.....	11	....	92.5	1.58	1.46	3.04	1.08
Totals and means....	137	1.17	88.7	1.93	1.73	3.66	1.11

TABLE 4
PRELIMINARY MEAN HOURLY VALUES OF IONOSPHERIC DATA,
WATHEROO MAGNETIC OBSERVATORY, 1939

120° east meridian time (h)	h_{F_1} (km)	h_{F_2} (km)	f_E^o (mc/sec)	$f_{F_1}^o$ (mc/sec)	$f_{F_2}^o$ (mc/sec)	f_{min} (mc/sec)
00.....	....	272	....	....	5.35	....
01.....	....	269	....	....	5.12	....
02.....	....	266	....	....	4.83	....
03.....	....	264	....	....	4.60	....
04.....	....	267	....	....	4.35	....
05.....	....	274	....	....	4.18	....
06.....	....	266	1.53	....	4.68	....
07.....	238	262	2.35	4.43	6.45	0.69
08.....	232	277	2.94	4.61	7.92	0.83
09.....	228	288	3.30	4.75	8.83	0.94
10.....	221	299	3.51	4.98	9.48	0.99
11.....	218	307	3.63	5.12	9.88	1.02
12.....	220	308	3.69	5.16	10.05	1.04
13.....	222	306	3.68	5.14	10.15	1.04
14.....	225	302	3.59	5.04	10.14	1.01
15.....	229	290	3.41	4.80	10.05	0.97
16.....	231	275	3.07	4.52	9.71	0.87
17.....	235	259	2.52	4.46	9.28	0.75
18.....	....	241	1.74	....	8.59	0.63
19.....	....	238	....	....	7.51	....
20.....	....	245	....	....	6.67	....
21.....	....	256	....	....	6.08	....
22.....	....	267	....	....	5.72	....
23.....	....	269	....	....	5.51	....

Observatory to Washington was discontinued. Subsequently arrangements were made through the State Department of the United States and the Australian Minister for Defense whereby weekly cabled messages of magnetic character would be allowed to be dispatched by the United States Consul in Perth on our behalf, and since then this plan has been satisfactorily continued.

Visual observations of solar activity with the Hale spectrohelioscope were continued on all possible days during the three half-hour periods assigned by the International Solar Committee, and monthly reports have been prepared and transmitted to Washington.

The usual meteorological observations as outlined in previous reports were made daily, and all the self-recording meteorological instruments were kept in continuous operation. Besides being used in the control of the Observatory's recording instruments, the information is supplied monthly to the Australian Commonwealth Weather Bureau at Melbourne as in previous years. Included in the meteorological observations are daily quantitative determinations of condensation-nuclei, using the Aitken nuclei-counter.

Scientific data and information as to equipment and technique were supplied, on request, to collaborators in Australia and elsewhere. Co-operation in ionospheric research continues between the Observatory and the Commonwealth Radio Research Board. Parkinson attended the Conference of Physicists and Astronomers held in Melbourne during August 1939, and also meetings, in Perth, of the West Australian Section of the Institute of Physics.

The tabulation and reduction of observatory-data are practically current, although toward the end of the report-year, owing to changes of staff and other causes, some slight arrears were accumulated.

The need for further office space, especially felt after the inauguration of the ionospheric research program, and the desirability of a more orderly and accessible arrangement of the growing library of the Observatory led to the erection of a new office, removed from the variation-observatory and therefore unhampered by restrictions as to the nonmagnetic character of its contents. This building was completed and occupied in October 1939. The old office was converted into a library, in which adequate space for the storage of books and periodicals will be provided for many years to come.

The building which formerly housed the atmospherics recorder (on loan from the Com-

monwealth Radio Research Board), given to the Observatory on the completion of the research in atmospherics, was removed to another site and was outfitted as a darkroom for all the photographic work of the Observatory. It also houses the anemograph which was formerly mounted in the auxiliary quarters.

In order to provide a necessary margin of electrical power, and also from considerations of economy, a Stover Diesel engine-generator of 15 horsepower was installed at the end of 1939; the necessary fuel storage-tank and filter-system were also erected. The Kohler engine-generators continue in service during times when the Diesel is under overhaul or being serviced.

Replacement of the overhead power and general wiring system of the Observatory by an underground, lead-covered cable-system was about 50 per cent completed. The buildings, grounds, and auxiliary equipment were kept in order.

The Observatory has been fortunate in the continued enjoyment of the good will and cooperation of government departments and private individuals, without whose ready aid the prosecution of the program would be almost impossible, especially under present world conditions. Specific mention should be made of the officials of the Commonwealth Postmaster-General's Department, especially the Senior Radio Inspector in Perth, Mr. G. A. Scott, for their interest in our work and for special permission to continue the ionospheric transmissions in spite of the rigorous curtailment of general radio activity in Australia necessitated by the war. The Commonwealth Department of Trade and Customs has continued its beneficent attitude by allowing the importation of necessary equipment and supplies free of duty. The United States consular staff in Perth have been most helpful in the matter of cabling our weekly magnetic-character messages. Senator H. B. Collett, C.M.G., has rendered valuable assistance by making representations in the Observatory's interests to government departments in Canberra; Professor A. D. Ross, of the University of Western Australia, has continued his interest in the Observatory and has given assistance in various ways.

Parkinson continued as Observer-in-Charge, with Prior as first assistant. Chamberlain, junior observer until March 31, 1940, resigned to take an appointment at the Mount Stromlo Solar Observatory and was succeeded by C. H. Muhling on April 13, 1940. McCarthy continued as junior observer throughout the report-year. George

continued as mechanic, with McCall as assistant mechanic. The successful prosecution of the comprehensive and increasing program is evidence of the continued energy and efficiency of all members of the staff.

Huancayo Magnetic Observatory. The Observatory is situated in latitude $12^{\circ} 02' 7''$ south and longitude $75^{\circ} 26' 4''$ west of Greenwich, in the central valley of the Peruvian Cordillera at an elevation of 3350 meters (11,000 feet) above sea-level.

F. T. Davies was Observer-in-Charge through September 1939, at which time he resigned for active service with the British forces. H. W. Wells has been Observer-in-Charge since October 1939, with W. Culmsee and R. C. Coile as assistants, the latter joining the scientific staff at the Observatory in October 1939. Among the Peruvian employees, T. Astete, A. Macha, and V. Murga continued as clerical assistants throughout the year.

Eight major instruments and several meteorological recorders, as listed below, were operated during the year.

Two magnetographs, one an Eschenhagen, the other a la Cour rapid-run type, were operated continuously. Control of base-lines was obtained by weekly absolute magnetic observations. Scale-values for declination and horizontal intensity of the Eschenhagen magnetograph were determined electrically once each week, and the scale-value for vertical intensity was determined electrically three times each week. Scale-values for horizontal intensity and vertical intensity of the la Cour magnetograph were determined electrically once each month. An additional la Cour horizontal-intensity variometer was operated at low sensitivity with the Eschenhagen magnetograph. Monthly reports of the more important magnetic disturbances were forwarded to the Washington office.

Air-potentials were recorded with standard potential-gradient apparatus and scale-values were determined twice each month. Reduction-factors were obtained by comparison with potentials measured over open, level ground at quarterly intervals.

Air-conductivities (positive and negative) were continuously recorded and scale-values were determined every two weeks. The installation of a synchronous motor-drive operated from the 60-cycle, alternating-current supply in place of the variable-speed, direct-current motor in the calibration-equipment resulted in greater accuracy and simplicity of calibrations.

Earth-current potentials were recorded continuously with the Leeds and Northrup apparatus. The use of two separate systems of north-south and east-west electrodes was continued.

The horizontal-component Wenner-type and vertical-component Benioff-type seismographs were operated. The Wenner seismograph was operated continuously, recording earth-movements in the north-south and east-west planes. Following overhaul and slight modification by the manufacturer, the Benioff apparatus was reinstalled in January 1940. Operation of this instrument is now very satisfactory. Analyses of the more important seismic disturbances were made regularly and code-messages were transmitted to the Washington office by amateur radio. The Peruvian earthquake of May 24, 1940, which caused appreciable damage along the coast, was also felt at the Observatory although no damage was done. The north-south instrument gave a complete recording of earth-tremors for this date. The east-west instrument, however, was thrown off scale with the initial movement, and did not return to normal recording position.

A Compton-Bennett cosmic-ray meter recorded cosmic-ray intensities continuously. Reduced cosmic-ray intensities during periods of strong magnetic disturbances are evident from casual examination of the records.

The Hale spectrohelioscope was used daily, as conditions of clouds permitted, for observation of the Sun. The assigned daily periods of observation for Huancayo are from $15^{\text{h}} 30^{\text{m}}$ to 16^{h} and from $16^{\text{h}} 30^{\text{m}}$ to 17^{h} GMT, according to the international program. Monthly reports of results of spectrohelioscope observations were prepared. These formed the basis for quarterly reports forwarded to the International Astronomical Union from the Washington office.

The multifrequency ionospheric recorder was operated continuously except for short intervals necessary for maintenance and minor modifications or repairs. Scalings and tabulations of critical frequencies and virtual heights of the several ionospheric regions were kept current. Quarterly reports giving summaries of average ionospheric conditions and trends were forwarded for publication in the *Journal of Terrestrial Magnetism and Atmospheric Electricity*. An annual report was prepared, summarizing the results of the second full year of continuous recording. It was shown that the generally predominant features and characteristics for 1939 were similar to those reported for 1938. These include the annual trend of F_2 -region penetra-

TABLE 5

PRELIMINARY MONTHLY MEAN VALUES OF ATMOSPHERIC-ELECTRIC ELEMENTS,
HUANCAYO MAGNETIC OBSERVATORY, 1939

MONTH	NO. SELECTED DAYS	POTENTIAL-GRADIENT		AIR-CONDUCTIVITY, UNIT 10^{-4} ESU			
		Reduction-factor	Value (v/m)	λ_+	λ_-	$(\lambda_+ + \lambda_-)$	(λ_+ / λ_-)
January.....	4	....	42.8	4.58	4.56	9.14	1.00
February.....	2	....	48.2	3.82	3.91	7.73	0.98
March.....	4	1.20	53.9	3.92	3.80	7.72	1.03
April.....	6	....	43.8	5.02	5.14	10.16	0.98
May.....	10	....	52.5	4.10	4.19	8.29	0.98
June.....	10	1.18	56.6	4.27	4.30	8.57	0.99
July.....	6	....	49.3	4.77	5.00	9.77	0.95
August.....	10	1.20	56.4	4.83	5.36	10.19	0.90
September.....	5	....	52.6	3.93	3.88	7.81	1.01
October.....	5	....	46.1	4.69	5.01	9.70	0.94
November.....	3	....	49.5	4.95	5.26	10.21	0.94
December.....	3	....	51.9	4.59	4.58	9.17	1.00
Totals and means....	68	1.19	50.3	4.46	4.58	9.04	0.98

TABLE 6

PRELIMINARY MEAN HOURLY VALUES OF IONOSPHERIC DATA,
HUANCAYO MAGNETIC OBSERVATORY, 1939

75° west meridian time (h)	h_{F_1} (km)	h_{F_2} (km)	f_E^o (mc/sec)	$f_{F_1}^o$ (mc/sec)	$f_{F_2}^o$ (mc/sec)	f_{min} (mc/sec)
00.....	....	251	....	....	8.36	....
01.....	....	249	....	....	7.73	....
02.....	....	252	....	....	6.91	....
03.....	....	254	....	....	6.09	....
04.....	....	258	....	....	5.38	....
05.....	....	259	0.76	....	4.88	0.65
06.....	....	270	1.76	....	6.50	0.87
07.....	241	259	2.66	4.58	9.30	1.08
08.....	232	278	3.27	4.99	10.86	1.39
09.....	222	289	3.65	5.21	11.51	1.69
10.....	215	304	3.85	5.36	11.39	2.00
11.....	211	314	4.00	5.43	11.01	2.14
12.....	209	319	4.04	5.46	10.86	2.19
13.....	207	318	3.95	5.38	10.86	2.14
14.....	209	310	3.79	5.23	10.92	2.02
15.....	214	297	3.54	4.95	10.97	1.70
16.....	231	286	3.08	4.59	10.97	1.26
17.....	....	260	2.49	....	10.86	0.96
18.....	....	296	1.46	....	10.54	0.94
19.....	....	345	0.78	....	9.79	0.70
20.....	....	333	....	....	9.27	....
21.....	....	298	....	....	9.14	....
22.....	....	273	....	....	8.92	....
23.....	....	259	....	....	8.75	....

tion-frequencies, and the unusual fact that the F_2 -region virtual heights seem to assume the features of typical variations of both northern and southern hemispheres, with no pronounced local seasonal effects.

A fixed-frequency ionospheric recorder operating on 4800 kc/sec was constructed and installed at the Observatory in August 1939. Since then, the equipment has been rebuilt into panels of permanent construction. The results have been most useful for analyses and interpretations of radio fade-outs; the latter are frequently associated with a sharp increase in horizontal intensity, similar in appearance to a sudden commencement.

Special ionospheric recordings of radio-wave polarization were conducted in January 1940, using a rotatable antenna-system. The results, which have been reported in a separate paper, confirm and extend the conclusions made from other tests conducted here by Wells in 1935.

Radio communication with John B. Morgan's amateur radio station, W3QP (Blue Bell, Pennsylvania), was maintained by the Observatory's station, OA4U, to forward magnetic data, reports of earthquakes, and other information of a scientific nature. Following the order of the Federal Communications Commission prohibiting United States communications with foreign countries by amateurs, this material has been broadcast from OA4U with satisfactory results.

The 6-kw Diesel engine-generator for power-supply continues quite satisfactory. It is operated continuously except for short periods of maintenance or overhaul. Associated equipment, including the direct-current voltage-control system used to automatically adjust the output of the Diesel to the varying load-requirements, continues to be satisfactory.

Observations of barometric pressure, maximum and minimum temperatures, relative humidity, rainfall, cloudiness, and direction and velocity of wind were made daily at 08^h, 75° west meridian time. Measurements of the air-content of condensation-nuclei were made daily at the same hour. Continuous records were obtained with barograph, thermograph, hygrograph, anemometer, and sunshine-recorder.

Computations and tabulations of magnetic, atmospheric-electric, earth-current, ionospheric, and meteorological studies were kept current. Records and tabulations were forwarded each month to the Washington office, together with seismograms, cosmic-ray records, and solar data obtained with the spectrohelioscope. The Ob-

servatory continued to supply copies of monthly tabulations of meteorological results (including barometric pressure, direction and velocity of wind, and sunshine) to the Servicio Meteorológico Nacional del Perú and also to the Centro Geográfico Departamental de Junín, Perú.

In accordance with the resolution passed by the Association of Terrestrial Magnetism and Electricity at Washington in September 1939, adopting 3-hour-range indices (K) to characterize the variation in the degree of irregular magnetic activity throughout each day, this Observatory has been providing tabulations of K -indices since January 1940.

Preliminary mean values of the magnetic elements for all days of 1939 as deduced from the Eschenhagen magnetograms, referring the elements to the north-seeking end of the needle and reckoning east declination and north inclination as positive, are: declination, +7° 00'4; horizontal intensity, 0.29553 CGS unit; vertical intensity, 0.01162 CGS unit; inclination, +2° 15.1. The preliminary values for the annual changes in the magnetic elements during 1938.5 to 1939.5 are: declination, -4'2; horizontal intensity, -19 gammas; vertical intensity, -5 gammas; inclination, -0'5.

Preliminary monthly mean values of the atmospheric-electric elements are given in table 5. Reduction-factor observations were made quarterly.

Mean hourly values of ionospheric data for the several ionospheric regions are given in table 6, where h refers to virtual height and f indicates penetration-frequency, while the subscripts show the particular ionospheric region. All data refer to the ordinary wave-component only.

The successful continuance of the program has been possible because of the hearty cooperation of the scientific staff, with the definite assistance of the Peruvian employees.

COOPERATION WITH OTHER OBSERVATORIES

Cheltenham Magnetic Observatory, United States. The cooperative program with this Observatory under the direction of the U. S. Coast and Geodetic Survey was continued. CIW sine-galvanometer 1 and CIW earth-inductor 48 were used for absolute standards in horizontal intensity and inclination. With the generous assistance of Observer-in-Charge Ludy and G. Hartnell of the Observatory's staff, the precision cosmic-ray meter furnished automatic records of

cosmic-ray intensity, and the CIW perminvar vertical-intensity induction-variometer gave dependable records of magnetic vertical intensity to April 11, 1940, when it was returned to the Department and set up in the Standardizing Magnetic Observatory. The necessary controls of the magnetic equipment used in Guatemala and on the U. S. Antarctic Expedition were obtained with the cooperation of the Cheltenham Observatory staff.

Apia Observatory, Western Samoa. The Department continued cooperation with this Ob-

1939 there occurred 117 days of zero-character with a mean value of 116.9 volts per meter. These results and a summary of the meteorological elements are given in table 7. The annual average hourly values in volts per meter based on the monthly means are as follows: 90, 86, 89, 90, 95, 103, 145, 217, 219, 153, 121, 105, 100, 94, 93, 90, 88, 93, 119, 166, 146, 121, 101, 89.

Tucson Magnetic Observatory, United States. The Department's equipment for recording atmospheric potential-gradient, positive and negative air-conductivities, and earth-currents,

TABLE 7

POTENTIAL-GRADIENT AND METEOROLOGICAL SUMMARY, APIA OBSERVATORY, 1939

MONTH	POTENTIAL-GRADIENT		METEOROLOGICAL ELEMENTS					
	No. zero-days	Value (v/m)	Pressure (inches)	Temp. (°F.)	Rainfall (inches)	Rel. hum. 9 A.M. (per cent)	Sunshine (hours)	Wind velocity (miles/hr.)
January.....	2	110	29.788	78.3	59.57	83	175.3	7.8
February.....	4	109	29.776	79.4	18.65	81	149.9	9.2
March.....	5	112	29.792	78.6	17.95	84	186.4	4.7
April.....	12	127	29.833	79.1	9.00	81	208.0	6.4
May.....	10	118	29.842	78.9	2.35	78	274.7	5.6
June.....	10	110	29.874	77.9	1.57	74	272.0	5.8
July.....	18	139	29.878	78.1	3.28	75	302.1	5.5
August.....	16	128	29.829	79.0	2.13	74	291.5	7.9
September.....	5	112	29.882	78.1	7.87	80	203.2	5.7
October.....	15	120	29.839	79.3	11.17	71	250.4	7.5
November.....	12	112	29.784	80.1	5.98	75	256.1	4.8
December.....	8	108	29.791	79.3	11.66	75	202.7	4.7
Totals and means..	117	117	29.826	78.8	151.18	78	2772.3	6.3

servatory through its Acting Director, H. B. Sapsford, and staff in the program in terrestrial magnetism and atmospheric electricity. This Observatory also undertakes observations in other fields of geophysics, including meteorology and seismology.

CIW magnetometer 9 and CIW earth-inductor 2 were on loan for absolute observations of declination, horizontal intensity, and inclination. Continuous photographic records were obtained of declination, horizontal intensity, and vertical intensity during the report-year. Declination and horizontal intensity were recorded with Eschenhagen variometers and vertical intensity with a Godhavn balance.

Atmospheric potential-gradient was measured with a Benndorf electrometer. Standardization-observations for reduction-factor confirmed that the previous factor of 1.00 still applied. During

through the cooperation of the U. S. Coast and Geodetic Survey, was efficiently operated and controlled by Observer-in-Charge J. Hershberger and R. F. White. The preliminary scaling of the atmospheric-electric observations was done by Mrs. G. Dewey in part-time service of the Department. The preliminary monthly and annual values of the atmospheric-electric elements are given in table 8.

The line-connections to the electrodes were maintained through the courtesy of the Bell Telephone Laboratories. The earth-current records are normally complete for the year. Earth-current records for this and previous years were extensively used in an investigation of earth-current activity with the sunspot-cycle.

Cape Town Magnetic Observatory, South Africa. Cooperation with this Observatory of

the Magnetic Branch of the Trigonometrical Survey of the Union of South Africa was continued through the loan of apparatus. Control of declination, horizontal intensity, and vertical intensity is maintained using CIW magnetometer 17 with earth-inductor attachment.

Royal Alfred Observatory, Mauritius, Indian Ocean. The loan of CIW marine-inductor 4 and galvanometer to this Observatory was continued for the control of the vertical-intensity records.

College, Alaska. Professor E. H. Bramhall continued work in the laboratory preparing equipment for recording ionospheric conditions.

kept current at the Tucson Magnetic Observatory. Scale-values are being examined and analyzed as a function of temperature and time and appropriately assigned by Sherman preliminary to the computing of the final values of the three elements, potential-gradient, positive conductivity, and negative conductivity. At present it seems that: (a) the potential-gradient reduction-factor may with sufficient precision be regarded as a constant, namely, 1.24 during 1931 to 1939; (b) in general, the scale-value for both posi-

TABLE 8
PRELIMINARY MONTHLY MEAN VALUES OF ATMOSPHERIC-ELECTRIC ELEMENTS,
TUCSON MAGNETIC OBSERVATORY, 1939

MONTH	NO. SELECTED DAYS	POTENTIAL-GRADIENT		AIR-CONDUCTIVITY, UNIT 10^{-4} ESU			
		Reduction-factor	Value (v/m)	λ_+	λ_-	$(\lambda_+ + \lambda_-)$	(λ_+ / λ_-)
January.....	15	....	57.7	2.34	2.14	4.48	1.09
February.....	19	1.27	62.1	2.10	1.90	4.00	1.11
March.....	27	1.24	47.6	2.54	2.49	5.03	1.02
April.....	15	1.22	46.8	2.76	2.58	5.34	1.07
May.....	28	....	47.6	3.01	3.00	6.01	1.00
June.....	24	....	52.5	2.77	2.76	5.53	1.00
July.....	4	....	55.7	2.68	2.49	5.17	1.08
August.....	9	1.22	53.0	2.30	2.20	4.50	1.05
September.....	18	1.29	50.9	2.72	2.66	5.38	1.02
October.....	19	....	44.8	2.73	2.50	5.23	1.09
November.....	15	....	49.0	2.84	2.67	5.51	1.06
December.....	22	....	51.1	2.56	2.44	5.00	1.05
Totals and means....	215	1.25	51.6	2.61	2.49	5.10	1.05

REDUCTION OF MAGNETIC DATA

The Section of Observatory-Work continued the reduction of the magnetic data from Watheroo and Huancayo observatories. Final reductions were accomplished for the year 1938. Work is now progressing on current magnetic records for 1939 and 1940.

The final values of the magnetic elements for all days during 1938 and the preliminary values during 1939 for the Watheroo and Huancayo observatories are shown in table 9.

REDUCTION OF ATMOSPHERIC-ELECTRIC AND GEOELECTRIC DATA

Scalings of average hourly deflections and computations of monthly scale-values were

tive and negative conductivity varies with deflection, whereas that for potential-gradient is independent of deflection except for a small part of the time; (c) an increase of temperature of 1°C increases the scale-value about 1 per cent for both conductivity-apparatus. This is about the same as the temperature-coefficient found for the equipment used at Watheroo, Huancayo, and College, and on the *Carnegie*. Because of the good thermal insulation of the atmospheric-electric observatory at Tucson, the diurnal range in temperature inside, as well as other short-period changes, is so small that only the corrections for the variation of temperature from month to month are important.

The final checking, reduction, and compilation of the earth-current tabulations were kept current by Rooney. More revision was required than usual. At Watheroo defective insulation on one of the lines necessitated the scaling of all days for two months of 1938

from records for the alternate line for the same component. At Tucson an undetected interchange of the lines between the Observatory and the distant electrodes necessitated a revision of about a quarter of the records for 1939.

TABLE 9

ANNUAL VALUES OF THE MAGNETIC ELEMENTS AT THE WATHEROO AND HUANCAYO MAGNETIC OBSERVATORIES AS BASED UPON MAGNETOGRAAMS FOR ALL DAYS, 1938 AND 1939

YEAR	DECLINA-TION, <i>D</i>	INCLINA-TION, <i>I</i>	INTENSITY-COMPONENTS					LOCAL MAGNETIC CONSTANT, <i>G</i>
			Hori-zontal, <i>H</i> (γ)	Total, <i>F</i> (γ)	North-south, <i>X</i> (γ)	East-west, <i>Y</i> (γ)	Vertical, <i>Z</i> (γ)	
WATHEROO MAGNETIC OBSERVATORY								
1938.....	3° 26'3 W	64° 23'3 S	24682	57100	24638	-1480	-51489	35665
1939.....	3 21.0 W	64 23.7 S	24687	57127	24645	-1442	-51517	35678
HUANCAYO MAGNETIC OBSERVATORY								
1938.....	7 04.6 E	2 15.6 N	29572	29595	29346	3643	1167	29577
1939.....	7 00.4 E	2 15.1 N	29553	29586	29332	3605	1162	29559

REDUCTIONS OF CARNEGIE DATA

Final revisions of manuscripts for three volumes of physical, chemical, and biological results obtained during the last cruise of the *Carnegie* are under way. Unfortunately, limited personnel and the urgency of other parts of the Department's program, especially

the development of the Cyclotron Laboratory and its equipment, slowed progress on these manuscripts. The numerous diagrams and tabulations have been completed for offset reproduction.

INSTRUMENT-SHOP

The work of the instrument-shop totaled approximately 12,800 man-hours by Steiner (in charge), instrument-makers Lorz, Haase, Huff, Roes (from February 5, 1940), and A. M. Schmidt, carpenter A. Smith, and apprentice Fogel. This included the construction of new equipment and experimental apparatus, repairs and improvements of instruments, apparatus, buildings, and grounds, and stock, special, and miscellaneous items.

The major projects were the primary standard of the electromagnetic measuring device,

experimental ionospheric apparatus, improvements to main building and Experiment Building, miscellaneous packing, and improvements, cleaning, and repairs to shop.

The primary standard required complete machining of all the duralumin castings, leaving only the various smaller parts to be constructed, such as bearings for rotating coil, rotating-coil drive-mechanism, and electrical connections from both the rotating and the primary coils. Special measuring devices were made, including an invar ring for supporting

the special micrometers, complete metal shielding around coil and appurtenances from body radiation during measurements, and spherical-ended pyrex length-standard. The Edelmann base for the primary standard was completely rebuilt and all magnetic parts were replaced. Difficulty was experienced in obtaining sound nonmagnetic brass castings from commercial foundries, and it was necessary to use the Department's small foundry. It was found essential that virgin metals be used in alloying nonmagnetic brass, since the contents must be known precisely. The conventional method of foundry practice was followed, using a thick covering of charcoal over the surface of the copper to prevent the copper from oxidizing, and, when the copper becomes molten, adding the lead, tin, and zinc, stirring with a transite stirring rod, and pouring at a temperature between 1825° and 1875° F.

A third ionospheric equipment was completed. A special high-speed driving mechanism was made for use at Kensington during the eclipse of April 7, 1940, and was then disassembled and shipped to the Huancayo Magnetic Observatory for use

during the eclipse of October 1, 1940. A visual frequency-band indicator was also constructed. Other ionospheric apparatus included: new cam layout and calibrating device; scaling glasses and three scaling-glass supporting frames for ionospheric traces. Experience with the three equipments at the observatories and at Kensington showed that an improved design of the band-switch contactors was desirable; contactors of the new design were made, as also other replacement parts requested by the observatories.

Galvanometers 38X to 45X were improved by new alnico magnet-systems; Schulze earth-inductor 2 and galvanometer 28A, belonging to the Apia Observatory, were overhauled; alterations were made to the precision cosmic-ray meter at Cheltenham; instruments were put in order for the First Expedition of the U. S. Antarctic Service; a specially designed ionization-chamber was made for the Guatemalan Volcanological Expedition. Other items included equipment for Atomic-Physics Observatory and cyclotron; shipments for observatories and cooperating organizations; development of, and special type for, automatic justifying typewriter.

MISCELLANEOUS ACTIVITIES

Members of the staff took active part as delegates and officers in scientific meetings and organizations and on numerous special committees. Among these were: Seventh (triennial) Assembly of the International Union of Geodesy and Geophysics, at Washington; Sixth Pacific Science Congress, at Berkeley and San Francisco; conventions of the American Institute of Electrical Engineers and Institute of Radio Engineers, at Swampscott and Boston; Executive Board of the International Union of Scientific Radiotelegraphy; Wave-Propagation Committee of the Institute of Radio Engineers; American Geophysical Union, at Washington; National Advisory Committee on Aeronautics; American Physical Society; Philosophical Society of Washington. Active share was taken in several physics colloquia in and near Washington. Notes regarding lectures and ad-

dresses will be found in the section on "Publications" given for each branch of work.

Preparations for, and successful realization of, the Washington Assembly of the International Union of Geodesy and Geophysics, in September 1939, required much effort and time on the part of a number of the staff, who undertook the responsibility for the extensive office arrangements necessary at this Assembly of 719 delegates and guests from twenty-six nations and from the United States. The meetings of the Union and of its seven Associations were devoted almost exclusively to the presentation and discussion of 492 scientific reports and papers and the consideration of resolutions pertaining to the progress of geophysics on a coordinated basis in all parts of the world.

Since May 1940, an increasing portion of the time of many of the staff has been given

to questions of national defense, particularly as regards applications of specialized knowledge to the solution of certain problems. These services and use of the facilities of the Department have been provided without cost to the government.

Attention was given to plans for, and preparation of equipment to be loaned to, the National Geographic Society—University of Virginia Expedition to the South Sea Islands. Active part was taken in the successful effort to have one of the cutters of the U. S. Coast Guard assigned for the use of the expedition for one year. Unfortunately the outbreak of war in Europe made it necessary to postpone this geophysical survey.

Exhibit. The Department's contributions to the annual exhibition of scientific work of the Institution were: (a) the Earth's magnetism and its long-time or secular changes; (b) high-energy transmutation of uranium atoms, uranium fission, and radioactive tracers; and (c) cosmic rays, in part. The first was constructed by the Museum of Science and Industry in New York following detailed plans and specifications furnished by the Department (McNish and Vestine); included was a model showing the representation of the Earth's field and its secular variation by clusters of dipoles at appropriate depths and positions. The second (Tuve and associates) demonstrated the effects of radioactive tracers resulting from the uranium-fission process and their potential value for radically new experiments in biology. The third was sponsored by the Institution's Committee on Coordination of Cosmic-Ray Investigations and was planned by Research Associate T. H. Johnson and constructed by the Bartol Foundation of the Franklin Institute with some help from the Department.

Library. The effect of the outbreak of hostilities in Europe early in the report-year was reflected in the decrease of publication abroad and in the difficulties encountered in the procurement of books and journals from most of the countries involved. Despite these unfavorable conditions, accessions during the year amounted to 409, bringing the number of accessioned books and pamphlets to 25,761.

The indexing of publications received and of articles of interest in current scientific journals, numbering about 100, as set forth in previous reports, was continued.

Librarian Harradon edited contributions in foreign languages and contributed letters, notes, abstracts, and the quarterly lists of recent publications to the *Journal of Terrestrial Magnetism and Atmospheric Electricity*. Much translation was done, chiefly in connection with the meeting of the International Union of Geodesy and Geophysics. In collaboration with G. E. Boesch and A. Girard, Jr., a guidebook of Washington and the program of the Assembly were translated into French.

Scientific papers by members of the staff through 1940 totaled 1940. Reprints of published articles were mailed from time to time to interested institutions and individuals. This distribution was in charge of Dove. A large number of reports and manuscripts were typed by Dove, who also acted as secretary to the Director and continued in charge of the general correspondence files.

As in the past, the facilities of the library were extended to investigators and students from various institutions and governmental bureaus. Interlibrary loans have been made with other libraries and cordial and reciprocal relations have been maintained, particularly with the Library of Congress.

Office administration. The usual correspondence, placing of orders, and matters concerned with accounting—all in charge of M. B. Smith, Administrative Assistant—were considerably increased during the year because of the construction of the cyclotron building and its equipment and because of matters relating to the Institution's Committee on Coordination of Cosmic-Ray Investigations. Various matters in connection with the meetings of the International Union of Geodesy and Geophysics were looked after. Through the courtesy of the U. S. Coast Guard, it was possible to ship to the Godhavn Observatory, in Greenland, cosmic-ray supplies as well as magnetograph supplies and chemicals which could not be forwarded as usual from Copenhagen.

Effective assistance was received as usual

from Moats and Singer (resigned April 9, 1940), from Dove, and from the newly appointed stenographers and typists, Miss D. N. Gottshall (from September 20, 1939) and Miss R. C. Dermody (from March 25, 1940). Capello, property-clerk and stenographer, had

charge of shipments and inventory and prepared many manuscripts. Numerous illustrations, drawings, charts, and sketches for articles, lantern-slides, and exhibits were prepared by Hendrix. The photographic work required was done by Ledit.

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SPECIAL PROJECTS: TERRESTRIAL SCIENCES

COMMITTEE ON COORDINATION OF COSMIC-RAY INVESTIGATIONS. *Progress report for the period July 1939 to June 1940.* (For previous reports see Year Books Nos. 32-38.)

The formation, purposes, and policies of the Committee on Coordination of Cosmic-Ray Investigations of the Institution are given in detail in Year Book No. 38 (pp. 335-349). As heretofore, the Committee has enjoyed the privilege of consultation during the past year, either through personal contacts or through correspondence, with the many interested investigators in all parts of the world who are listed in that report.

Statements evaluating cosmic-ray research were solicited from many capable and distinguished American men of science who have given much time, effort, and service to this field. The following condensed statement is based upon the judgment of the members of the Committee and upon these communications.

The study of cosmic radiation offers an effective approach to the investigation of the atomic nucleus and is one of the few major means of determining relations between fundamental physical entities—electrons, mesons (mesotrons), and protons; that is, the basic structure of matter. The results on the distribution of cosmic-ray energies, indicating the association to some extent of maxima and minima of the energy-curve with the most abundant elements, are fundamental, and the verification or refutation of these is of first importance. The conclusions already drawn as to the electrical character of cosmic rays, the effects of magnetic field and of magnetic storms, solar effects, and possible origin in our own galaxy, and the discovery of the meson as a secondary radiation produced in the upper air have stimulated in remarkable degree development of special apparatus and of associated techniques—cloud-chambers, tube-counters, radiosondes, equipment for flights in the stratosphere, and many others; these, in themselves, represent a profitable return for the funds and services

that have been devoted to research in cosmic radiation.

The Committee since its organization has stressed that side of research calling for world-wide cooperation, for example, the recording and discussion of time-variations over long periods as an approach which must give, and has already given, evidence of cosmical interrelations and of the composition of cosmic radiations. These developments and potentialities have attracted many men of unusual qualifications and ability and of all nationalities, so that now over a hundred investigators of highest attainments and many assistants are devoting their time to this subject. Among these we are especially fortunate in having so many representing our foremost universities and research institutions. Already hundreds of important contributions have been made as a result of the support given by these organizations and by the Committee through the Carnegie Corporation of New York and the Carnegie Institution of Washington. Special grants have also been stimulated from organizations such as the American Philosophical Society, and funds, as well as services, have been generously contributed by various universities, including, among others, the University of Chicago, the California Institute of Technology, and the Bartol Research Foundation. In all these the Carnegie Corporation of New York, through the Carnegie Institution of Washington, and the latter itself, in the pioneer work of the Department of Terrestrial Magnetism over the seas, have taken a prominent part not only in providing funds but also in providing services.

An important step in the program sponsored by the Committee has been the improved treatment of data at the Department of Terrestrial Magnetism on a sound statistical basis, as regards both regular and

irregular time-variations and world-wide variations in cosmic radiation. Unique features resulting from this treatment are the evidence afforded by the material for critical discussion of the possibility of a permanent solar magnetic field, and the evidence for the existence of current-systems far outside the Earth's atmosphere during magnetic storms.

Under the existing disturbed conditions in the world we may not look too far ahead, but should do everything possible, consistent with the demand upon scientific personnel in connection with problems of national defense, to insure that we may not too greatly sacrifice future research interests in the field of cosmic rays for the immediate present. The provision for keeping alive such investigations of cosmic radiation may be expected to yield results second to none in importance in the advance on the frontiers of the physical sciences and in the understanding of complex cosmical phenomena.

The following summary and appended reports give details of the year's results and progress.

Instruments. The Carnegie Institution's precision recording cosmic-ray meters continued operating at the following stations: Cheltenham Magnetic Observatory of the U. S. Coast and Geodetic Survey, meter C-1, George Hartnell in charge; Huancayo (Peru) Magnetic Observatory of the Institution's Department of Terrestrial Magnetism, meter C-2, H. W. Wells in charge; National Astronomical Observatory of Mexico at Teoloyucan, D. F., meter C-4, Dr. Joaquin Gallo in charge; Amberley Branch of the Christchurch (New Zealand) Magnetic Observatory of the Department of Scientific and Industrial Research of New Zealand, meter C-5, J. W. Beagley in charge; Godhavn (Greenland) Magnetic Observatory of the Danish Meteorological Institute, meter C-6, K. Thiesen in charge.

Installation of meter C-3 at Climax, Colorado, was again delayed owing to defective insulation of the collector-system, which required the complete dismantling of the

ionization-chamber. The instrument has been operated at Cheltenham since April 17, 1940, for comparison with meter C-1 at that station before installation at Climax.

Two of the Millikan-Neher meters were loaned for use on the First Expedition of the U. S. Antarctic Service. These were operated on board the Expedition's vessels during the journey to the base. Thereafter one was kept in constant recording while the other was used in several air flights.

Investigations. Professor A. H. Compton at the University of Chicago was responsible for a cosmic-ray symposium, the proceedings of which were published as a special number of the *Reviews of Modern Physics*. During this year there was completed under his guidance a four-year investigation of the intensity of cosmic rays on the Pacific Ocean by Professor D. H. Loughridge and Paul Gast, with the cooperation of the Northland Transportation Company between Seattle and Juneau. These studies led to a correlation of the fact that cosmic radiation is more intense in winter than in summer with the difference in atmospheric temperature. The production of mesons at high altitudes was found to increase rapidly with altitude. Among these, low-energy mesons are of special interest because they are distinguishable in mass and ionizing power from electrons. The properties of the meson were further determined by the use of a large cloud-chamber in a powerful magnetic field and through the continuation of balloon-experiments. Professor Compton's associates also gave considerable time to the study of changes in cosmic-ray intensity, using chiefly the data obtained from the seven model-C recording ionization-meters.

Mr. Forbush continued analysis of the world-wide effects at the several stations and found excellent agreement between these effects for Huancayo and Teoloyucan and between those for Cheltenham and Christchurch. He also finds a significant difference between the general trend in cosmic-ray intensity at Huancayo and Teoloyucan and that at Cheltenham and Christchurch which may indicate an important change in the

latitude-effect with time. Analysis of the 27-day waves in cosmic-ray intensity was also extended to include the data for 48 complete solar rotations at one pair of stations and 40 complete rotations at another pair. This material makes possible a more critical search for the existence of a persistent 27-day wave in cosmic-ray intensity at high latitudes, the existence of which would indicate a permanent solar magnetic field. In 87 out of 98 cases now available from the data for Cheltenham, Huancayo, and Teoloyucan, the average cosmic-ray intensity for the five international magnetically disturbed days of each month, C_D , was less than the average for the five magnetically quiet days, C_Q . A high correlation, +0.90, was found between the monthly differences ($C_D - C_Q$) for each pair of stations. Mr. Forbush gave full time to the reduction, analysis, and interpretation of the cosmic-ray data obtained at the Committee's five stations. He was assisted throughout the report-year by F. R. Eldridge, Jr.

Professor V. F. Hess, of Fordham University, devoted his attention to meson-disintegration and air-mass effects at sea-level and to preparations for obtaining a series of cosmic-ray measurements on board ship from New York to Valparaíso.

The objectives of the continued research by Dr. Thomas H. Johnson, of the Bartol Research Foundation, were to obtain further evidence of the nature of the primary cosmic radiation before its encounter with the Earth's atmosphere, to investigate the processes of interaction of mesons with matter, to study the factors affecting the lifetime of a meson before its final spontaneous disintegration into an electron, and finally to obtain further evidence of the production of mesons by protons. These objectives were pursued through balloon-flights, coincidence-counter measurements of the proper life of the meson, and studies with a large Wilson cloud-chamber. In connection with these objectives, several valuable technical developments were made.

Dr. S. A. Korff, of the Bartol Research Foundation, looked after cooperation with the U. S. Antarctic Service, and in his report

gives some preliminary account of the work so far done by that Service on its first expedition. Through radio-balloon observations he obtained material for further investigation of the generation of soft rays and the influence of surrounding matter on measurements in the stratosphere. The program of flights using counters capable of detecting slow and fast neutrons was continued, as were also the studies of the properties of proportional counters and the production of neutrons by cosmic radiation. In the investigation of neutron-intensities, he found it necessary to standardize neutron-counters and neutron-sources.

Professor R. A. Millikan and his associates at the California Institute of Technology reported upon the following projects: the measurement through 45 balloon-flights in India, extending nearly to the top of the atmosphere, of the latitude-effect in the equatorial belt; the building of a large cosmic-ray cloud-chamber of high resolving power to obtain more accurate data on the mass and nature of the meson; repetition with modern and improved techniques of the Millikan-Cameron measurements of the ratio of the absorption-coefficients for cosmic rays of air and water, in the hope of computing from these data the lifetime of the meson; and completion of the sea-level measurements between Seattle and the Strait of Magellan for the study of seasonal effect on cosmic-ray intensity at sea-level and the interpretation of this effect in terms of the lifetime of the meson.

Dr. M. S. Vallarta at the Massachusetts Institute of Technology has undertaken the investigation of the motion of cosmic-ray particles in the magnetic field of the Earth, the theory of magnetic storms, and related problems.

Perhaps the best evidence of the activity of the investigators to whom the Committee has extended some help during the year may be found in the bibliographies which follow their reports and show the articles published from July 1, 1939 to June 30, 1940.

As in past years, the Committee has been favored by generous assistance on the part

of all of those who have been specifically mentioned and many others. Particular acknowledgment is to be made to the directors and staff-members of the organizations which continued to give their facilities for the program involving continuous records by the precision model-C cosmic-ray meters, namely, the Danish Meteorological Institute, the National Astronomical Observatory of Mexico, the Department of Scientific and Industrial Research of New Zealand, the United States Coast and Geodetic Survey, and the Carnegie Institution of Washington.

W. S. ADAMS
J. A. FLEMING, *Chairman*
F. E. WRIGHT

COSMIC-RAY MAGNET

Robert B. Brode

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A detailed study by means of models has been made for the cosmic-ray magnet. As a result of this study, the original plans for the use of a 350-kw motor-generator set were given up in favor of a more efficient iron-yoke magnet. The final design involves the use of about 5000 pounds of steel and 3000 pounds of copper. The magnet is water-cooled by layers of copper tubing in the winding. The thermal contact is fairly efficient between the windings and this water-cooling because of the use of square copper wire with thin woven-glass insulation.

All the materials for the construction have been ordered and are in the Physics Department shop. Steel yokes for the magnet have been machined at a local shipyard and the other parts have been machined in our shop. The bobbins on which the coils will be wound have been finished and the actual winding has been begun.

Measurements made by Mr. Bagley, research student, on the writer's old magnet show considerable scattering due to the uncertain curvature in the small magnetic field available. However, they indicate a meson-mass of the order of magnitude of 100. This is considerably smaller than previous estimates. With ten times the magnetic field in

the new magnet, these results will be much more reliable, and it may be possible to identify mesons of more than one mass if this should prove to be the cause of the scattering. Unpublished results of Dr. Sen Gupta, a student of Professor Blackett at Manchester, resulting from measurements in argon, are in good agreement with the nitrogen measurements at this laboratory. Fermi's theory of the influence of the dielectric constant of the gas should become apparent for electrons above 10^9 electron-volts and for mesons above 10^{10} electron-volts. It is anticipated that the Carnegie magnet will give some information in this energy-region.

REPORT ON COSMIC-RAY RESEARCH AT THE UNIVERSITY OF CHICAGO

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Cosmic-ray symposium. The year 1939-1940 opened with an international congress of students of cosmic rays at the University of Chicago. Since the congress under the auspices of the Physical Society of London in 1934, no comparable group of specialists in this field had been brought together. The discussions gave new impetus to the work of the American investigators and summarized the results obtained by the European investigators before most of their studies were stopped by the war.

The chief interest of the members of the congress was centered around the use of cosmic rays as a tool for investigating the properties of the fundamental particles, protons, mesons, electrons, neutrinos, etc., and the structure of atomic nuclei. It was felt that in cosmic rays, because of their very high energy, lies our most hopeful approach to these problems. Attention was given also to such questions as the factors which affect the intensity of cosmic rays, the production of secondary radiation, and the composition and properties of the cosmic-ray particles. The proceedings of the congress were published as a special number of the *Reviews of Modern Physics*.

Cosmic rays on the Pacific Ocean. This year marked the completion of a four-year investigation of the intensity of cosmic rays on the Pacific Ocean. During this period, almost without interruption, observations have been taken with a model-C ionization-meter over the route from Tasmania to Alaska. The final stage of 16 months' readings was obtained by Professor D. H. Loughridge and Paul Gast, with the cooperation of the Northland Transportation Company, between Seattle and Juneau. This study has given a much more detailed knowledge of the variation of cosmic rays with latitude, from magnetic latitude 53° south to 62° north.

The immediate occasion for undertaking this investigation was to learn whether the northerly motion of the Earth through space with the rotation of the galaxy gives rise to an excess of cosmic rays in the northern hemisphere. Approximate calculation predicts a difference of 0.4 per cent if the rays originate beyond the Milky Way. The observations do indeed reveal an excess of about this amount; but the difference is completely accounted for (± 0.1 per cent) by the lower temperature of the air in the northern hemisphere along the route followed. It thus appears probable that the cosmic rays do not come to us from beyond the Milky Way. They seem rather to share the general motion of our neighboring stars.

Between the equator and 40° latitude there is an increase in cosmic-ray intensity of about 10 per cent. Above this latitude, when account has been taken of temperature-differences, no perceptible further increase occurs. In accord with Lemaitre and Vallarta's theory of the action of the Earth's magnetic field on electrical particles approaching the Earth, this means that primary particles with energies of less than six billion electron-volts are not able to produce effects that can traverse the atmosphere. We have found, however, that the primary cosmic rays produce mesons close to the top of the atmosphere and that a meson loses slightly less than three billion electron-volts in passing through this amount of ma-

terial. Our observation thus supports the view that the mesons are produced in pairs of roughly equal energy when the primary rays enter the upper layers of the atmosphere, and that these mesons form the penetrating rays which reach the Earth's surface.

Radioactive disintegration of mesons. In our Pacific Ocean studies it was observed that in both hemispheres cosmic rays were more intense in winter than in summer. Following a suggestion of earlier investigators, this difference was correlated with the difference in atmospheric temperature. Blackett of Manchester showed how such a dependence on temperature should be present if mesons, produced high in the atmosphere, should disintegrate with a mean life comparable with the time required to reach the ground. Other lines of evidence for such disintegration were also brought forward. Finally, in an experiment carried out by Bruno Rossi, on an expedition from our laboratory to Mount Evans, the existence of such radioactivity of the meson was established.

Rossi counted the mesons received at 10,000 feet elevation, and then at 14,000 feet elevation with a mass of carbon over the counter-tubes equivalent in mass to the 4000 feet of air between the two stations. The counting rate at the upper station remained considerably greater. This was due to the loss of mesons between the two stations as they disintegrated en route. The average path traversed before disintegration was found to be about 6 miles, which means a life of about 30 microseconds. In a second similar experiment, in the summer of 1940, measurements were made of the life of mesons of such relatively low energy that they are stopped in about 20 cm of lead. Their life was found to be 10 microseconds. According to the theory of relativity, the rate of a moving clock should be in proportion to its total energy. On this basis the life of a meson at rest should be close to 2 microseconds. This determination of the lifetime of the faster and slower mesons constitutes a striking demonstration of the variation of rate of a moving clock.

Production of mesons at high altitudes. Since mesons are radioactive, it is evident

that they cannot come to the Earth from great distances, but must rather be produced in the atmosphere itself. Theories have been developed which indicate a high probability of production of mesons when protons or neutrons traverse matter, and a somewhat lower probability of production by photons or electrons of very high energy. Our earlier experiments had shown no appreciable meson-production by electrically neutral rays at sea-level or even on a mountain at 14,000 feet. Airplane experiments by Wilson and Schein showed, however, that such meson-production by neutral rays does occur at altitudes above 20,000 feet. During the past year W. P. Jesse, Marcel Schein, and E. O. Wollan have sent recording counter tubes to very high altitudes with balloons to study this phenomenon. They find that meson-production increases rapidly with altitude, and shows no evident diminution even at an atmospheric pressure of only 2 cm. At this altitude the number of mesons is at least as great as Millikan's estimate of the number of incoming primary particles.

These experiments indicate also the presence of many mesons of low energy at high altitudes. Such low-energy mesons are of especial interest, because they are distinguishable in mass and ionizing power from electrons. At sea-level they are exceedingly rare. Gerhard Herzog accordingly developed a cloud-chamber and a permanent magnet suitable for use in an airplane, and with W. Bostick made three successful flights. The photographs taken between 25,000 and 30,000 feet show large numbers of slow mesons, their production in pairs, and their occasional stopping in a thin plate of copper.

These photographs and similar ones taken by Bostick on Mount Evans show evidence of an occasional high-speed electron emitted from the end of the meson-path. In most cases, however, no such electron-track is visible. It would thus appear that when a meson stops in solid matter the probability of its capture by a process that does not give rise to the emission of an electrically charged ray may be greater than that of radioactive

disintegration with the emission of an electron. Both processes are predicted by Yukawa's theory of the meson.

Properties of mesons. Continuing experiments begun by Anderson, Blackett, and Jones, Donald Hughes has made a new and more precise study of the energy-distribution of the mesons at ground-level, using a large cloud-chamber in a powerful magnetic field. The most probable energy is about a billion electron-volts, with very few having energies less than 0.2 billion, and about 13 per cent having energies greater than ten billion electron-volts.

Hughes established what has for some time been suspected, that at sea-level positive mesons exceed negative mesons in number by about 25 per cent. The ratio of the numbers is nearly independent of the energy-range considered. It seems reasonable to relate this excess of positives to the well-known excess of positive primaries, as shown by the excess of cosmic-ray particles coming from the west. This lends support to the view that some mesons are produced by the direct action of protons.

Balloon experiments by Jesse, Schein, and Wollan from Chicago and Texas indicate that at high altitudes the latitude-effect on mesons is only about a third as great as on the soft component of cosmic rays. The difference between these two stations is due to the primary particles of about five billion electron-volts energy which penetrate the Earth's magnetic field at Chicago but not at Texas. Thus it seems that primaries of this energy are relatively more effective in exciting the soft component (electrons and photons), and that it must be the higher-energy primaries that give most of the mesons.

In order to account for a change in the slope of his absorption-curve of cosmic rays at depths of over 300 feet below ground, V. C. Wilson suggested that mesons with enough energy to reach these great depths may lose energy by radiation, as electrons do at lower energies. This hypothesis has been supported by certain theoretical calculations. Wilson has accordingly carried out counter-experiments in tunnels and mines above and

below depths of 300 feet to study the nature of the penetrating rays. Though he finds that at both depths the counters record highly penetrating electrical particles, showers are relatively more abundant at the greater depths. A cloud-chamber to photograph these deeply penetrating particles is now in operation.

Changes in cosmic-ray intensity. Using chiefly the data obtained from the seven model-C recording ionization-meters that are being operated under the joint supervision of the Carnegie Institution of Washington and the University of Chicago, studies have been made of the factors connected with changes in the cosmic rays.

Most striking is the discovery of the major importance of the air-distribution in the atmosphere. The correlation with temperature pointed in this direction. Loughridge and Gast, from data taken on the Pacific Ocean, found marked effects caused by the approach of cold or warm "fronts." Now, by comparing the fluctuations of the cosmic rays at sea-level at Cheltenham with the changes in the meteorological balloon data taken near Washington on the same days, N. F. Beardsley finds 10 per cent of the variations are associated with those at Huancayo (world-wide changes), 15 per cent with changes in the barometer (total air-mass), and 40 per cent with changes in the vertical distribution of the air-mass (caused chiefly by temperature-changes). A change in the mass of air above 12 km is accompanied by more than twice as great a change in cosmic rays as is the same change in the air-mass near the ground. This relatively great importance of air-mass at high altitudes is just what is to be expected from the rapid disintegration of the mesons after they are produced in the upper atmosphere, and is in qualitative accord with the meson-decay observation of Rossi.

W. P. Jesse has studied the changes in cosmic rays close to the top of the atmosphere, by balloon-flights made approximately once a month. Such data should be independent of atmospheric temperature. The observed changes of some 10 per cent follow, however, the changes observed at Huancayo, and seem

to show a seasonal effect with a sharp drop in the spring. If further tests show that this seasonal effect is real, it may perhaps be ascribed to some interaction between the magnetic fields of the Earth and Sun.

Of the possible periodic effects, we recognize clearly one following the solar day and a 28-day period. Changes following the sidereal day, or the year-after correction for temperature-effects, are relatively small if present at all. Special attention has been given to the 28-day period. This seems to be associated with the Sun's rotation, and if so, indicates an action on cosmic rays far outside the Earth.

More complete discussions of these and other cosmic-ray experiments carried on in our laboratories during the past year are given in the publications listed in the bibliography which follows this report.

Personnel. Our cosmic-ray research is so closely integrated that all parts of it have profited by cooperation with the Carnegie Institution of Washington. The following research associates, instructors, and research fellows of the University of Chicago have given most of their time to this work: W. P. Jesse, Marcel Schein, E. O. Wollan, V. C. Wilson, Donald J. Hughes, Bruno Rossi, Ardis T. Monk, Elmer Dershem, N. F. Beardsley, P. S. Gill, and Victor Regener. Drs. Gerhard Herzog and Gerhart Groetzinger, as guests of the laboratory, have devoted their time to cosmic-ray studies. As graduate students, F. L. Code and Winston Bostick have made contributions of special value. Particular mention should be made of the active aid given to our cosmic-ray program by Professor D. H. Loughridge and Paul Gast, of the University of Washington; Professor Victor F. Hess and his colleagues, of Fordham University; Professor J. C. Stearns, of the University of Denver; Professors R. D. Bennett and M. S. Vallarta, of Massachusetts Institute of Technology; Professor G. R. Tatum, of Baylor University; Professor H. V. N. Hilberry, of New York University; Dr. John A. Fleming and S. E. Forbush, of the Carnegie Institution of Washington; Professor Joaquin Gallo, of the Uni-

versity of Mexico; and R. N. Turner, of the R.M.S. *Aorangi*.

Cosmic-ray studies in war time. In planning for the continuation of this active program at a time when the nation must gird itself for defense, we must note that the study of cosmic rays is of no considerable practical value. Like astronomy, it is concerned rather with the better understanding of the world. Nevertheless, we consider this study as second to none in human value. The properties of the fundamental particles, the study of which is a main objective of cosmic-ray investigations, present a problem of scientific importance strictly comparable with that of the structure of atoms or of molecules. That the field is newer than chemistry merely indicates the greater need for its study.

Except under the greatest stress, the long-time programs of recording cosmic-ray data should not be allowed to lapse, for their value pyramids with the years. Other important projects under way should be completed if at all possible. On the other hand, new projects in this field can now be undertaken only where most urgent. We hope, nevertheless, to be able to keep enough of this work going to enable us to begin afresh when the way is again clear.

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STATISTICAL INVESTIGATIONS OF
COSMIC-RAY VARIATIONS

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Reduction of data. As in previous years, the scalings of hourly values of cosmic-ray ionization, bursts, and barometric pressure were kept current, together with adequate check-measurements by an independent observer, for the records obtained at Cheltenham, Godhavn, and Huancayo. Reductions of daily mean values of ionization to constant barometric pressure were also kept current for Cheltenham, Christchurch, Godhavn, and Huancayo.

The reductions to constant barometric pressure of the bihourly mean values of ionization for each day were completed through May 1940 for Cheltenham and through September 1939 for Godhavn. Reduction to constant barometric pressure of the bihourly means of ionization at Huancayo was also begun.

The barometric coefficients were heretofore derived through correlation between daily means of ionization and barometric pressure for intervals of a month or more. The coefficients thus obtained, for Godhavn and for Christchurch, agreed excellently with those recently obtained by correlating the bihourly means of ionization and of barometric pressure averaged for each of two groups of selected 24-hour intervals. The 24-hour intervals in one group were all characterized by rapidly increasing barometric pressure, those in the other by rapidly decreasing barometric pressure. No significant difference was found between the barometric coefficients derived from the two groups. Also the baro-

metric coefficients for Cheltenham, Christchurch, and Godhavn were found to agree within the statistical uncertainty of about 5 per cent. Since these three stations are at the same elevation and all in high latitudes, there is no theoretical reason to expect differences in the barometric coefficients. The good agreement actually found provides a reliable check on the absolute sensitivity of the meter at these locations.

By correlating the daily means of ionization of barometric pressure averaged for many selected periods of a week during which the greatest obtainable changes in pressure occurred, a barometric coefficient for Huancayo was obtained in excellent agreement with the somewhat less certain value obtained from the ratio of the amplitude of the large 12-hour solar wave in barometric pressure to that in the cosmic-ray ionization without correction for pressure.

Intercomparison of cosmic-ray meters. Intercomparison of cosmic-ray meter C-3, which the Committee planned to install at Climax, Colorado, with meter C-1 at Cheltenham was delayed owing to defective insulation of the collector-system. This was caused by direct contact to the collector-system of one of the neoprene washers used for argon-seals at the ends of the amber insulators. This defect necessitated the complete dismantling of the ionization-chamber and the design of retainers to prevent the neoprene gaskets from squeezing out of place and making contact with the collector-system.

For reliable performance the insulation-resistance of the collector-system should not be less than 10^{15} ohms. To measure reliably the insulation-resistance up to 10^{16} ohms, a procedure was devised which could also be applied to the meters at the several cosmic-ray stations. Using this procedure, the resistance of the collector-system, after the amber insulators had been polished with chamois and Putz pomade and washed in ether, decreased from about 5×10^{15} ohms to about 3×10^{14} ohms in 9 days. Since the latter value was wholly inadequate, the insulators were removed and carefully repolished but not washed in ether. Following this treat-

ment, the insulation remained unchanged at about 2×10^{16} ohms for 6 weeks.

To eliminate inconvenience and uncertainties in data due to argon slowly escaping from the ionization-chamber, even at such a rate as could only be detected by readings on the argon-pressure gauge over a period of months, a vacuum technique was applied which insured the absence of any argon-leak (except at the main gasket where the neck of the chamber attaches to the bomb, where no difficulty has yet been experienced with any of the meters) sufficiently large to cause a decrease in argon-pressure as great as one pound per square inch per year with the initial pressure at 750 pounds per square inch.

The main ionization-chamber of this bomb, which was used at Cheltenham until February 1937, then had anomalous saturation-characteristics. Also the ionization was seriously affected by changes in temperature. For these reasons particular care was taken to insure that the geometrical arrangement of the collector-system was identical with that in other meters. As a result the saturation-characteristics of the main chamber and of the balance-chamber are now excellent.

Meter C-3 has been operated continuously at Cheltenham since April 17, 1940, for comparison there with meter C-1. The ratio of sensitivities of the two meters, calculated from carefully measured constants, agreed well with that derived from an analysis of the observed changes in recorded ionization. This ratio also agreed well with that obtained from a comparison of the increase in ionization in each of the meters produced by a radium sample.

Statistical analysis of the comparison-data obtained since April 17, 1940, indicates a systematic change in one of the meters of about 1 per cent of the total cosmic-ray intensity. Since this change is of the same magnitude as the amplitude of the seasonal variation, it is essential to determine the cause.

Barograph for Huancayo. At Huancayo the 24-hour and 12-hour solar waves in barometric pressure each have an amplitude of about 1 mm of mercury. Thus the corrections

for barometric pressure to the observed diurnal variation of cosmic-ray intensity are especially large and require reliable barometric-pressure data. Although no serious defect exists in the performance of the ordinary pen-recording barograph from which these data are now obtained at Huancayo, a more open time-scale, a greater sensitivity, and a greater freedom from friction are desirable in a barograph. These characteristics are also much desired by several investigators of the lunar-barometric tides. The Paulin barograph, originally installed in cosmic-ray meter C-2 at Huancayo, but damaged in transit, has been repaired and carefully compared with a standard barometer at the Department. Because of its excellent performance it is planned to mount this instrument at Huancayo to record photographically with an open time-scale and sufficient sensitivity.

Cosmic-ray intensity and magnetic activity. That the world-wide changes in cosmic-ray intensity are associated with magnetic activity is demonstrated by the fact that the cosmic-ray intensity is nearly always lowered on days of magnetic disturbance. To facilitate description of the quantitative results obtained as evidence of this association, let the average cosmic-ray intensity for the five magnetically quietest and for the five magnetically most disturbed days in each month be designated by C_Q and C_D , respectively, and let $D = (C_Q - C_D)$. Using all available data at Cheltenham, Huancayo, and Teoloyucan through August 1939, 98 values of D were derived, of which 87 were negative with an average several times greater in absolute value than the average of the 11 positive values. Since it is well known that the horizontal component of the Earth's field is always less on magnetically disturbed days than on quiet days, these changes in cosmic-ray intensity are consistent with the hypothesis that the changes result from alterations of cosmic-ray trajectories produced by the Earth's external magnetic-disturbance field.

Using values of D for each of the same 25 months at Cheltenham, Teoloyucan, and Huancayo, the correlation-coefficient between

each pair was found to be about +0.90. This high correlation provided a determination of the ratio of D at each pair of stations, which was in approximate agreement with that derived from earlier analyses of the world-wide changes (*Physical Review*, vol. 54, p. 975, 1938). Results of the above investigation are soon to be published in the *Journal of Terrestrial Magnetism and Atmospheric Electricity*.

World-wide changes in cosmic-ray intensity. In a previous investigation (see reference above), it was found that if the 12-month wave in cosmic-ray intensity was removed from the data for each station except Huancayo, for which the 12-month wave was absent, the curves through the resulting monthly means were remarkably similar for all stations. This investigation has now been extended to include all data now available. The results indicate no significant change in the 12-month waves at any of the stations. The curves through the monthly means after deducting the 12-month wave are still remarkably similar for Huancayo and Teoloyucan, and also for Christchurch and Cheltenham. However, a considerable divergence has occurred between the trend of the curves for Huancayo and Teoloyucan and that for Christchurch and Cheltenham. This divergence may possibly indicate an important change in latitude-effect with sunspot-cycle. The latitude-survey which Professor V. F. Hess plans to make using a Compton-Bennett meter on board a Grace Line steamer from New York to Valparaíso should provide data which, together with those which have already been obtained by Professor A. H. Compton in the Pacific, will determine whether any significant change in the latitude-effect has occurred at sea-level. Results of the recent investigation of world-wide effects are expected to be ready for publication soon.

Time-variations in burst-rate at Huancayo. A preliminary investigation of the rate of production of bursts at Huancayo indicates the existence of significant changes in the number of bursts per month. These changes

appear to follow the changes in total cosmic-ray intensity from month to month. Attempts to determine from the data at hand whether significant changes with time occurred in the energy-distribution of bursts proved fruitless because of the inevitable uncertainties and systematic errors in determining the actual size of the smaller bursts, and because of uncertainties in the corrections for electrometer-sensitivity. To facilitate future investigations of changes in burst-rate, arrangements have been made to maintain the electrometer-sensitivity of the meters constant.

On the 27-day variations in cosmic-ray intensity. The analysis of the 27-day and 13.5-day waves in cosmic-ray intensity reported at the Washington Assembly of the International Association of Terrestrial Magnetism and Electricity, September 1939, has now been extended to include the following number of complete solar rotations at each of the following stations: Cheltenham, 40; Christchurch, 48; Huancayo, 51. Harmonic analysis for each solar rotation has also been made for magnetic character-figure for the same period and for magnetic horizontal intensity at Huancayo. The correlation between the 27-day variations in cosmic-ray intensity at these three stations is high, again indicating the world-wide character of the 27-day variation in cosmic-ray intensity and its association with the 27-day variation in terrestrial magnetism. This additional material is now being subjected to statistical tests to determine whether, superposed on the quasi-persistent 27-day wave, a persistent 27-day wave exists in the data from Cheltenham and Christchurch. The existence of such a wave would, according to M. S. Vallarta and O. Godart (*Review of Modern Physics*, vol. 11, p. 180, 1939), indicate a permanent solar magnetic moment inclined to the Sun's axis of rotation.

On causes for the variability of the 24-hour waves in cosmic-ray intensity. The variability of the 24-hour wave in cosmic-ray intensity at Cheltenham derived from 155 magnetically quiet days (international character-figure $C \leq 0.2$) was compared with

that derived from 132 days with $C \geq 1.4$, and with that derived from 54 days with $C \geq 1.7$. The variability (square of two-dimensional standard deviation in the harmonic dial) for days with $C \geq 1.7$ was nearly twice as great as that for days with $C \leq 0.2$, whereas the variability for days with $C \geq 1.4$ was only about 12 per cent greater than that for days with $C \leq 0.2$. This indicates that the reliability of the average 24-hour wave from a given amount of available data cannot be materially improved by excluding days for which $C \geq 1.7$. Thus in determining the sidereal diurnal variation the most reliable average would be obtained by including all the data—a result which could not have been anticipated without the above test.

In addition, the variability of the 24-hour wave at Cheltenham was found to be nearly twice as great in winter as in summer, a result important to statistical tests for the reality of any sidereal wave in cosmic-ray intensity.

On the cause for the diurnal variation in cosmic-ray intensity at Huancayo. According to the theory of M. S. Vallarta and O. Godart (see reference above), the diurnal variation of cosmic-ray intensity at Huancayo should be due practically entirely to the system of ionospheric currents responsible for the diurnal variation in terrestrial magnetism. Since the latter at Huancayo is largely in the horizontal component, the Vallarta-Godart theory would require the diurnal variation in cosmic-ray intensity to be very similar to that in the horizontal magnetic component. However, the average diurnal-variation curve for cosmic-ray intensity at Huancayo, derived from complete records on 1330 days, differs significantly from that for the horizontal magnetic component and thus does not substantiate the Vallarta-Godart theory for the observed cosmic-ray diurnal variation at Huancayo.

Sidereal diurnal variation in cosmic-ray intensity. For three complete years at Cheltenham and four complete years at Huancayo the analysis of cosmic-ray data for the 24-hour and 12-hour sidereal waves in cosmic-ray intensity is now nearly completed.

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REPORT ON COSMIC-RAY PROBLEMS

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Work has been done on the following two problems with the aid of the grant from the Carnegie Institution of Washington.

Cosmic-ray measurements on board ship from New York to Valparaíso, with model-C meter. Arrangements with the Grace Line, Inc., of New York have been made concerning the installation of one of the Committee's large model-C meters on board the freighter *Santa Ana*. This instrument will be placed in a deckhouse erected amidships. The demountable deckhouse used within the last two years on board the steamship *Northland* on trips from Vancouver to Juneau (Alaska) by Professor Loughridge was shipped from Seattle via Panama to New York, where it arrived on June 29, 1940.

The cosmic-ray meter was sent from Seattle to Chicago in June. Professor Compton suggested that the overhauling of this instrument be done in his laboratory under his supervision. Therefore the writer and two collaborators, Fr. Berry, S. J., Associate Professor of Physics (Fordham University), and F. Bene-

detto, worked for several weeks in Chicago, acquainting themselves with the instrument and doing some of the most urgent necessary repairs. The first trip to Valparaíso is scheduled for September 1940.

Meson-disintegration and air-mass effects at sea-level. Professor Swann kindly authorized construction of an elaborate twin-counter telescope for the writer's measurements in the shop of the Bartol Research Foundation. This telescope will allow for continuous independent registration of mesons coming from the vertical by two sets of counter-trays with well-defined sensitive areas. The design was completed in May 1940; the telescope is under construction with the aid of a special grant from the American Philosophical Society.

STUDIES OF COSMIC RAYS

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The studies made during the past year under grants from the Carnegie Institution have had the following basic objectives: (1) to obtain further evidence of the nature of the primary cosmic radiation before its encounter with the Earth's atmosphere; (2) to investigate the processes of interaction of the penetrating cosmic rays, or mesons, with matter and to study the duration and the factors affecting the lifetime of a meson before its final spontaneous disintegration into an electron; and (3) to obtain further evidence of the production of mesons by protons. With these objectives in mind the following experimental investigations have been carried out.

Balloon-flights to study the importance of showers of simultaneous cosmic rays as a disturbing element in the measurement of cosmic rays from definite directions in the stratosphere. These studies have been made with the particular purpose of clarifying the interpretation of results reported last year (Year Book No. 38, p. 341) of balloon-flight measurements of the east-west asymmetry of the soft component cosmic rays in the stratosphere. Those measurements showed that,

unlike the hard component rays at sea-level, the soft component exhibited no east-west asymmetry, and it was concluded that the two components arise from different types of primary particle, the soft component from electrons, equally positive and negative, and the hard component from a predominantly positive proton component of the primary radiation. This interpretation was based upon the assumption that the counts recorded by a triple-coincidence cosmic-ray counter are produced by single cosmic rays passing in the direction of the counter-train, and that no appreciable part of those counts is due to showers of three or more simultaneous rays having directions other than that determined by the counter-train. In order to test the validity of this assumption, flights were made into the stratosphere from Swarthmore with instruments containing three coincidence-counters which were alternated between two positions, an in-line position and an out-of-line position. In the stratosphere the out-of-line counts measuring the effect of the showers never exceeded 5 per cent of the in-line counts, and it was shown that by far the greater part of the in-line counting-rate was produced, as originally assumed, by single cosmic rays having the direction of the counter-train. Hence the important conclusions drawn from the asymmetry studies in Panama stand unchallenged.

Coincidence counter-measurements of the proper life of the meson. Continuing the experiments outlined in last year's report, the intensities of mesons under equivalent absorbing layers of air and of other dense substances have been compared in order to estimate the importance of the time-of-flight factor and its effect upon the intensities. This has been done both for the total meson-intensity and for that part of it lying within a narrow range of low energies. In all energy-ranges the proper life of the meson has been found to be of the order of 2 to 3 microseconds and, within the accuracy of the experiments, to be independent of the energy. Some of the evidence, however, indicates that slow mesons are possibly being removed from

the beam by processes other than that of disintegration before they have been completely absorbed by ionization. Further tests of this possibility are being made in an experiment for comparing the absorption of low-energy mesons in carbon and in lead. An extensive set of data has already been obtained, but the final conclusions from these studies must await further analysis.

Studies with a large Wilson cloud-chamber. With funds provided jointly by the Carnegie Institution of Washington and the Bartol Research Foundation, a large Wilson cloud-chamber has been constructed and put into operation. This chamber is 23 inches in diameter and 6 inches deep. Up to the time of writing, 8000 stereoscopic photographs have been obtained showing mesons traversing three lead plates placed in the chamber whose thicknesses total 7 centimeters. The analysis of these photographs, and of others to be taken, is under way and has the following objectives: (1) to determine to what extent mesons occur in groups of two or more simultaneous rays resulting from production-processes taking place in material above or in the chamber; (2) to observe stopping and scattering of mesons in material in order to obtain a more accurate picture than that now available of the relative importance of these processes in their effect upon the quantity usually defined as the absorption-coefficient; (3) to observe the effect of mesons in producing nuclear transformations and artificial radioactivity; (4) to seek further evidence for the existence of protons in the cosmic radiation, for the production of mesons by protons, and for the inverse reaction, the production of protons by mesons. Some results in these far reaching studies have already been obtained. We have shown that the number of associated mesons, item (1), is considerably less than that indicated by the experiments of Braddick and Hensby (*Nature*, vol. 144, p. 1012, 1939). We have also found definite evidence for the existence of high-energy protons in the penetrating component of the cosmic radiation at sea-level. These experiments have pointed the way to

an experiment now being planned, for which funds have been provided by the Carnegie Institution of Washington, for the measurement of the proton-component of the cosmic radiation in the stratosphere.

The east-west asymmetry of the cosmic radiation in high latitudes and the balance of charge between the positive and negative rays occurring in the atmosphere. Cooperating in our program, Fred Seidl has made an extensive set of measurements of the east-west asymmetry at Troy, New York, in a latitude well above the knee of the latitude-effect where no primary asymmetry can be expected. An asymmetry of the order of 1 per cent is found at that station and can be used in calculating the excess of positive cosmic rays in the atmosphere. Results in accord with those reported by Hughes (*Physical Review*, vol. 57, p. 592, 1940) from measurements made with a large magnetic cloud-chamber have been obtained.

Technical developments. New devices developed in connection with our work with the cloud-chamber include a new type of mercury capillary arc, a new type of circuit for the control and operation of the arc, a flash-photometer for measuring the photographic exposure resulting from a flash, and a stereoscopic projector for viewing and measuring tracks photographed in the cloud-chamber. Certain novel features in the design and construction of the Wilson cloud-chamber have also been developed.

Personnel. This program has been carried on with the full-time cooperation of Dr. J. Griffiths Barry, M. A. Pomerantz, and Ralph P. Shutt. Acknowledgment is also made of the cooperation of Fred G. P. Seidl.

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COSMIC-RAY INVESTIGATIONS

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The following studies were carried on between July 1, 1939 and June 30, 1940, in the field of cosmic rays, with the aid of funds made available through the Carnegie Institution of Washington.

Cooperation with United States Antarctic Service. At the invitation of the U. S. Antarctic Service, a program of cosmic-ray observations to be made on the first U. S. Antarctic Expedition was prepared. This program was as follows:

a) Latitude-effect observations: Two cosmic-ray meters were operated on board U.S.S. *North Star* on its journey as supply-ship of the Expedition. One was a Millikan-type electroscope made available by the Carnegie Institution of Washington, and the other a Geiger counter-apparatus built at the Bartol Foundation. The electroscope was operated between Philadelphia and Little America, and the counter-apparatus remained on board the ship during its return voyage.

b) Variation of cosmic-ray intensity with elevation: One of the two Millikan-type meters has been carried to elevations of 21,000 feet in airplane flights at Little America. It is planned to continue the flight program.

c) Long-period installation: Two of the Millikan-type meters made available by the Carnegie Institution were installed in Little America for operation over the current year there. The records from these, when returned to the United States, will be analyzed for fluctuations correlating with magnetic storms, auroras, and external temperature.

The following results have been obtained to date: The latitude-effect, measured by both the counter and the electroscope, showed the familiar "knee" in the cosmic-ray intensity at geomagnetic latitude 38° south. South of

this point the cosmic-ray intensity continued to rise, as far as Little America (77° south geomagnetic), the southernmost point reached. The entire amount of this rise was found to be attributable to the decreasing external temperature, and hence to the lowering of that level in the atmosphere at which the penetrating component of the cosmic rays, namely, the mesons, is generated. It will be recalled that, in the southern hemisphere, no adequate observations have hitherto been made south of 45° .

It was found that a single Geiger counter, enclosed in a lead shield and using a suitable scaling and recording circuit, could be used as a reliable instrument for measuring the total cosmic-ray intensity. Since the counter counts the number of cosmic-ray particles, while the electroscope measures the ionization which the particles produce, a correlation of the two instruments provides new information regarding the average amount of ionization produced by each ray. The details of this are at present being studied. A preliminary calculation indicates that the ratio of electrons to mesons at sea-level does not vary with latitude south of 40° . This, taken in conjunction with the variation with external temperature, suggests that all the cosmic-ray electrons at sea-level are secondaries produced by the mesons.

Radio balloon-observations. (a) Generation of soft rays, and influence of surrounding matter on measurements in the stratosphere: On August 9, 1939, a flight was made in which a single Geiger counter was caused to occupy four positions with respect to lead blocks. The position of the counter was controlled by a small electric motor, and the complete cycle of positions was repeated every 5 minutes. This flight represents the first control-experiment made in the upper atmosphere in which the behavior of one instrument under four different conditions could be recorded.

It was found that the counting rate was increased when the counter was surrounded by lead blocks, as compared with the rate when lead was distant. The counting rate

was also increased, although not so much, when a lead block was placed above the counter. This was attributed to the generation of showers of secondaries by the cascade-processes produced by the cosmic radiation in the top lead block. The counting rate was also found to increase when lead was placed below the counter. This was due to the upward reflection, from the lower lead block, of rays incident on the block from above. Since high-energy rays tend to perpetuate their downward direction, the relatively large increase in the counting rate with the lead below the counter indicated that there was a very abundant radiation of low energy in the upper atmosphere. This radiation presumably consists of both charged particles and photons.

b) Flights with neutron-counters: The program of balloon-flights using counters capable of detecting slow neutrons, and other counters capable of detecting fast neutrons, was continued. Measurements of slow and fast neutrons in the upper atmosphere have been made, and the number of neutrons as a function of elevation was determined.

It will be recalled that boron-trifluoride counters, of the type described in last year's report, measure both slow and fast neutrons. The slow neutrons are found by counting the number of alpha particles which they produce by disintegrating the boron. The fast neutrons are detected by counting the number of recoil-nuclei which they produce as they pass through the chamber. Counters filled with gases which do not yield alpha particles through slow-neutron-induced disintegrations will count the fast neutrons only. Furthermore, the variation of the counting rate with the applied counter voltage makes possible a determination of the energy of the neutron which produces the recoil. Such a control-flight was made, the voltage on the counter being varied in a predetermined manner during the flight. Hence these studies reveal the ratio of fast to slow neutrons, as well as allowing measurements to be made of the energies of the fast neutrons. This series of flights is still in progress.

The preliminary result is that fast neutrons are quite abundant in the upper atmosphere; that of the fast neutrons, many lie in the energy-range between two and ten million volts or more; and that not all the fast neutrons are slowed down through collision-processes, some being captured at high energies. It was found that the neutrons were numerous, and indeed were about as abundant numerically as the charged particles in the cosmic radiation. Because the average neutron-energy is below ten million volts, however, as compared with the average energy of 20 or more times that amount exhibited by the charged cosmic-ray particles, the neutrons do not produce a large fraction of the cosmic-ray ionization.

c) Studies of proportional counters: The task of developing and studying the properties of proportional counters has been continued. It was found that the discharge of a counter can be made proportional to the amount of ionization occurring in the counter if it is operated in the proper voltage-range and if the gain of the amplifier detecting the pulses is properly adjusted. With care, the proportional counter can be made to be an accurate instrument with a wide variety of uses. In this work, it was developed for the purpose of studying the amount of ionization produced by various particles in the cosmic radiation.

d) Production of neutrons by cosmic radiation: The process by which the cosmic radiation produces neutrons has been investigated. Because of the theoretical instability and finite lifetime of neutrons, it seems highly probable that none of the neutrons observed in the upper atmosphere are primary particles, but rather that they have been produced by the high-energy cosmic radiation impinging on the upper atmosphere. The process by which this occurs is a new and important one in the domain of ultra-high-energy physics. A year ago it was suggested that this process was probably one in which the high-energy photons associated with the cosmic radiation caused neutrons to be evaporated out of the nuclei of nitrogen and oxygen of

the atmosphere. Further evidence for this is now at hand.

Since the high-energy photons are connected with, and themselves produce, large cascade-showers, it should follow that neutrons and large showers should be associated. An experiment was designed to test this by counting coincidences between the discharges of a neutron-counter and a shower-counter. Coincidences were observed, and were found to occur at a rate which enabled an independent calculation of the rate of production of neutrons to be made. On the average, one neutron is produced in every hundred showers.

The consequences of neutron-production and the life-history of the neutrons in the atmosphere have been investigated from the point of view of nuclear theory. It was shown that neutrons will be produced with energies of the order of ten to thirty million electron-volts. They will then lose energy, first by inelastic and then by elastic collisions, until when slow they are finally absorbed by nitrogen nuclei in the atmosphere.

e) Comparison of radioactive neutron-sources: In the course of the investigation of intensities of neutrons, it was found necessary to standardize neutron-counters and neutron-sources. A study was made of the comparative neutron-producing efficiencies of a number of radium-beryllium neutron-sources. It was found that each source had a different efficiency, and that radium-beryllium sources are more efficient than radon-beryllium sources. The gamma-ray intensity cannot be taken as indicating the expected neutron-intensity; the latter also depends on the amount of beryllium, the manner of mixing, and the amount of compression of the mixture. A procedure was developed by which rapid evaluations of efficiencies in terms of a given source as a standard could be made.

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STUDIES OF COSMIC RAYS

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The major researches which have been pursued and the results obtained between July 1, 1939 and June 30, 1940, in the cosmic-ray studies carried on at the California Institute

of Technology with the aid of funds supplied by the Carnegie Corporation of New York administered by the Carnegie Institution of Washington, may be very briefly summarized as follows: (1) the measurement through 45 balloon-flights in India, extending nearly to the top of the atmosphere, of the latitude-effect in the equatorial belt on the total incoming cosmic-ray energy and its east-west distribution; (2) the building of a large cosmic-ray cloud-chamber of high resolving power in the endeavor to obtain more accurate data than are now available on the mass and nature of the mesotron; (3) the repetition, with the aid of the most modern and improved techniques, of the original Millikan-Cameron measurements of the ratio of the absorption-coefficients for cosmic rays of air and water with a view to the computation from these data of the lifetime of the mesotron; (4) the completion of the sea-level measurements between Seattle and the Strait of Magellan of the seasonal, or "atmospheric temperature," effect on the sea-level intensity of cosmic rays, an effect now interpreted in terms of the lifetime of the mesotron.

Millikan, Neher, and Pickering's measurements in India. These measurements were made in collaboration with the British-Indian Meteorological Service in the three different latitudes of Bangalore (magnetic latitude 3° north), Agra (magnetic latitude 17°3' north), and Peshawar (magnetic latitude 25° north). In the various flights four different types of recording techniques were used, as follows: (1) Neher photographically recording electroscopes. These had to be recovered by the populace and sent back to us. They yielded the cosmic-ray energy coming in from all directions at all altitudes. (2) Neher-Pickering single-tube counters arranged to transmit back by radio to the home station the records of temperatures, pressures, and cosmic-ray shots passing the single counter-tube at all altitudes, and therefore yielding counts on all the shots from all directions passing through a given volume. The curves are similar to those yielded by (1) and served as a check upon the latter, but with certain significant differences due to the fact that

coincident shots are not registered by counters but are registered by electroscopes. (3) Neher-Pickering double counter-tubes arranged to register all the shots passing through the tubes *vertically* at all altitudes. (4) Johnson-Neher-Pickering techniques for measuring east-west effects up to very high altitudes. The returned instruments from these flights have not yet (July 6) all been received by us from the British-Indian Meteorological Office, so that the final results cannot now be reported. The preliminary results, however, seem to be favorable to the theory of the origin of the cosmic rays which led to these experiments.

Anderson and Neddermeyer cloud-chamber work. Most of the difficulties which appeared to confront the building of a huge magnet and cloud-chamber suitable for improving the resolving power of mesotron-measuring instruments have been overcome and there is now good promise of early results of significance. The job has been a long and difficult one and it is not yet finished.

Neher and Stever's measurements on the ratio of the absorbing power of air and water. In the original 1925 Millikan-Cameron measurements in high-altitude, snow-fed lakes, the difference in the altitudes of the two lakes chosen, namely, Muir Lake (altitude 11,900 feet) and Arrowhead Lake (altitude 5100 feet), was but 6800 feet. Nevertheless, there were definite, though small, indications of a higher absorption of cosmic rays by air than by water of the same mass, that is, an indication of the breakdown of the mass-absorption law. However, these were taken by Millikan and Cameron as falling within the limits of the experimental uncertainties inhering not only in the crudity of the electroscopes available at that time, but also in the smallness of the difference in altitude of the two lakes and particularly in the possible shielding effects of Mount Whitney upon Muir Lake situated just under its brow.

Accordingly, in the summer of 1939 Neher and Stever chose two lakes, one in the high Sierras and one near sea-level, of 12,000 feet difference in altitude, both unshielded by surrounding mountains; and, using the best of modern sensitive Neher electroscopes, they

obtained a ratio of 1.15 for the apparent absorptions of air and water. Interpreting this difference on the basis of the modern theory of the radioactive decay of the mesotron, they obtain for the mean rest lifetime of the mesotron 2.7×10^{-6} second. These results fix this value with a good deal of precision.

Millikan and Neher's measurements on the sea-level "atmospheric-temperature" effect on cosmic rays. In three round trips from Seattle to the Strait of Magellan, Millikan and Neher find between Los Angeles and the Strait, when all readings are reduced to a standard barometer, no seasonal or temperature-effect at all that is outside the limits of the daily, or even the semiweekly, fluctuations. But this was not the case between Los Angeles and Seattle. At the Seattle latitude the winter and spring readings were as much as 2 per cent higher than the summer and fall readings, this change at Seattle occurring while the intensity at Los Angeles was remaining essentially constant.

They interpret this effect, as Blackett had done before them in the case of the like measurements of Hess and Compton, in terms of the contraction in the thickness of the atmosphere in the northern latitudes in winter and the resulting increase in the effective air-path of the mesotron during its lifetime and hence of the ionization produced by it during its life.

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MOTION OF COSMIC-RAY PARTICLES IN THE GEOMAGNETIC FIELD

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The problem undertaken concerns the motion of cosmic-ray particles in the magnetic field of the Earth, the theory of magnetic storms, and related matters. The major portion of the work will be done using the differential analyzer. Because there have been delays in making available the new differential analyzer at the Massachusetts Institute of Technology, it has been possible so far only to take the necessary preliminary steps.

These preliminary calculations have been made during March to July 1940 by Dr. R. A. Hütner, Research Assistant at the Massachusetts Institute of Technology (paid from funds allotted by the Carnegie Institution of Washington). We are now ready to proceed with the analysis of the penumbra of cosmic radiation and the consequent determination of the energy-spectrum of primary rays, as well as with the theory of the galactic-rotation effect and that of magnetic storms, as soon as the new machine is made available.

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COMMITTEE ON STUDY OF THE SURFACE FEATURES OF THE MOON. *Progress report for the period July 1939 to June 1940.* (For previous reports see Year Books Nos. 26-38.)

A report on the results of visual measurements of the percentage polarization in beams of light from different parts of the moon's surface and in sunlight scattered by terrestrial materials at various phase angles is in preparation. Plans had been made to complete this report during the past winter, but other unexpected tasks interfered with the work.

Progress has been made in the topographic mapping of the important surface features of the moon by measurement of their slope angles and dimensions as recorded on the series of moon photographs taken in 1938 with the 100-inch telescope. This task is time-consuming and slow, but topographic maps are gradually being produced of many of the craters and mountains on the moon, and these will be useful later in connection with detailed physiographic studies of the moon's surface. An experimental viewing stereoscope has been built which is well suited to the study of lunar features with the aid of stereoscopic pairs of prints, and valuable information on their mutual relations has been obtained. The stereoscope permits use of a wide base and is equipped with a series of

lenses that enable the observer to use different degrees of magnification and to recognize relations between features that are not discernible on a single print or negative. The stereoscope is not equipped for photogrammetric measurements for the reason that the surface of reference is not a plane but an approximately spherical surface. The complications arising from this fact are so serious that, with the limited number of good stereoscopic pairs of photographs now available, construction of an instrument suitable for the measurements would not be justified.

Work on developing and testing the two photoelectric cell methods for measuring the percentage polarization in light scattered in different directions by lunar and terrestrial materials has been continued; a serious difficulty in this problem is the change in response of the photoelectric cell with change in azimuth of the plane of vibration of the incident light. This change in behavior of the photoelectric cell occurs when the direction of the incident plane-polarized beam of light is not perpendicular to the sensitive surface of the photoelectric cell. If, as is usually

the case, the surface of the cell is curved, it is difficult to avoid oblique incidence for part of the incoming beam which covers an appreciable area on the sensitive surface of the cell. One remedy is to make a special photoelectric cell with a flat window and a plane area of the sensitive surface opposite the window. Only this portion of the sensitive surface is to be used for the receiving surface, and on it the incident light will impinge normally. An alternative procedure is to depolarize the light before it reaches the photoelectric cell; this requires the use of a properly oriented, plane-parallel plate of glass or other transparent material that can be tilted at various angles to the line of propagation of the transmitted beam; the tilted plate introduces an amount of polarization into the transmitted beam just sufficient to compensate the polarization in the beam itself and thus to produce light that is nonpolarized. From the angle of tilt of the plate necessary to compensate the polarization in the beam it is possible to compute the percentage amount of polarization in the beam itself.

Final measurements of polarization by the photoelectric cell methods requiring the use of a direct-current amplifier or of an alternating-current amplifier must await tests with the special photoelectric cell and further improvement in the amplifying systems.

During the lunar eclipse of October 27, 1939 Dr. Edison Pettit, of Mount Wilson Observatory, measured the radiations from the moon with the aid of a vacuum thermocouple attached to the 20-inch reflecting telescope of 40 inches focal length and aperture ratio $F/2$. In these measurements lunar surface temperatures were determined by observations of galvanometer deflections produced by the thermocouple receiving the lunar radiations, either direct, or through a microscope cover glass 0.16 mm thick, or through a water cell 1 cm thick with quartz windows. For a small area near the center of the disk (0.85 radius from the north limb) Dr. Pettit found that the temperature fell from 371°K to

200°K ($+98^{\circ}\text{C}$ to -73°C) during the first partial phase and dropped slowly to 175°K (-98°C) during totality. At the beginning of totality the temperature fell at the rate of 30°C per hour; at the end of the first hour the rate was 7°C per hour. The rate of radiation during the partial phases was nearly proportional to the energy received, except for low temperatures.

On June 14, 1927 Drs. Pettit and Nicholson made 17 sets of measurements of the radiations from the moon during its eclipse. The 100-inch telescope was used and galvanometer deflections were obtained with cover glass, with water cell, and without absorbing screen (free deflections). At the start the free deflection was 617 mm; at the end of totality it was 1.48 mm; the sensitivity of the apparatus was varied by changing the electrical circuit of the thermocouple. The measurements were made on a small area near the edge of the moon's disk (0.05 lunar radius from the south limb). The values of lunar temperatures obtained do not differ greatly from those found in 1939 by Dr. Pettit, who adopted certain improvements in procedure by which 39 sets of readings were made and the sensitivity during the total phase was increased so that the deflection at the end of totality was 54 mm, as against 1.48 mm in the 1927 arrangement. In his report upon the 1939 results Dr. Pettit suggests several other improvements in procedure for measurement of the radiations during a lunar eclipse. It is hoped that these may be tested during a future eclipse and additional data secured on lunar surface temperatures and on the thermal characteristics of the materials exposed at its surface.

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CALIFORNIA INSTITUTE OF TECHNOLOGY, Pasadena, California. *Cooperative researches at the Seismological Laboratory.* (For previous reports see Year Books Nos. 37, 38.)

The Seismological Laboratory at Pasadena has continued attack during the past year on problems relating to local or southern California earthquakes, to earthquakes in other parts of the world and their bearing on earth constitution and structure and connected geo-physical problems, and to the new design and continuous improvement of seismic apparatus both for recording the oscillations in earthquakes customarily studied heretofore and for securing records of other elements in earthquake motion to which less attention has been devoted in the past.

The geographical distribution of earthquakes over the earth has been studied by others at various times, but a more complete and quantitative investigation was undertaken by Dr. Gutenberg and Dr. Richter, and a paper embodying the results was prepared. An estimate was made of the frequencies of shocks of various magnitudes. Those of magnitude 8 occur on the earth at the rate of about 1 per year, those of magnitude 7 at the rate of about 10 per year, and the rate increases with smaller magnitudes, so that at least 100,000 of magnitude 3 are estimated to occur each year. This latter estimate depends largely on the frequency of local shocks in the southern California region. The results as a whole depend mainly on the data accumulated at Pasadena and Huancayo. The purpose of the study was to determine what belts of the earth are most active seismically, what the relation of these seismic belts is to zones of recent mountain building and to the margins and interiors of the continental plates and ocean basins, and ultimately what are the causes and nature of the deformation affecting the earth's outer crust and perhaps its deeper shells.

The past year seemed to be a favorable time for taking stock of the data accumulated in recent years bearing on the distribution of earthquakes on the earth, since the spread of hostilities continues to eliminate one important seismographic station after another from the active list.

The investigation of the nature of air waves, begun by Dr. Gutenberg and Dr. Benioff through the use of recording micro-barographs, has been continued during the past year.

More data have been collected by Dr. Gutenberg and Dr. Richter, but not yet published, on the amplitudes of longitudinal waves in deep-focus earthquakes near the station at Huancayo. They confirm the results found earlier and published in the *Bulletin of the Seismological Society of America* for October 1939, indicating that there is a slight decrease in the velocity of longitudinal waves at a depth of about 80 km.

The problem of gradual changes of elevation of parts of the earth's crust, based upon tide-gauge readings, has been given further attention by Dr. Gutenberg. The findings suggest that there is a small rise in the level of all oceans at the rate of about 10 cm. per century. Also, the regions around the northern part of the Baltic Sea are moving upward at the rate of about 1 m. per century. The maximum uplift in North America appears to be in the neighborhood of Hudson Bay and probably exceeds 1 m. per century.

The registration of local or southern California earthquakes was continued uninterruptedly at the Pasadena Laboratory and the six outlying stations, and the results of the measurements and interpretation of these records proceeded as in former years. These data, like those derived from weather bureau or astronomical observatory records, gain increased value as they accumulate, particularly since seismic phenomena are spasmodic and a true cross section of the earthquake habit of a region like southern California is not gained from the records of a few years. We wish to determine the relative degree of activity of the different areas and of the different active faults; the depths of the foci of the shocks; the relation of the foci to the structure of the region; the relation of foreshocks and aftershocks to main shocks as to the significance of the time relation, the relative positions of

their foci on the fault, and their energy outputs, these bearing on the sequence of events and mechanical processes involved in generation of the shock; and the solution of the whole problem of the accumulation of stress during the intervals between major shocks and its release during the earthquake.

During the year July 1, 1939 to June 30, 1940, eight shocks of magnitude 4.5 and over (sufficient to cause damage in settled areas) occurred in the southern California region. (This excludes aftershocks of the larger earthquakes.) One of these, on December 27, originated near Long Beach and caused slight damage in that city. It demonstrates continued activity of the source of the destructive earthquakes of 1933, the Inglewood fault zone.

The most noteworthy shock of the year was the destructive Imperial Valley earthquake of May 18. Because of the development of a long fault trace with large strike-slip displacements (up to 15 feet), this is geodynamically the most significant earthquake in America since 1906. The records of the southern California stations, including the new installation at Palomar Mountain, were of great value in locating the epicenter of this shock, which is within the visible disturbed segment of the fault, instead of at one end, as was the case with the Long Beach earthquake of 1933. Owing to a confusion of rapidly succeeding earthquakes, no detailed study of aftershock seismograms is possible. The magnitude of the main earthquake is placed at about 6.5. The epicenter was southeast of El Centro. There was damage in all towns in Imperial Valley, much increased at Brawley by an aftershock later in the evening. Canals were seriously damaged, with consequent interruption of water service and some loss of crops. The total loss and damage may amount to as much as six million dollars. Nine persons were reported killed.

The nearly straight fault trace ruptured the surface for a known length of over 40 miles, extending from a point between Imperial and Brawley in a direction about S. 35° E. and crossing the international boundary about 8

miles east of Calexico and Mexicali. The fault and attendant phenomena of distortion and dislocation were carefully studied in the field by Dr. Buwalda and Dr. Richter, and the detailed results are being prepared for publication. The trace passed within a few kilometers and to the east of the instrumental epicenter. The southwest side of the fault is uniformly displaced northwest with reference to the northeast side; vertical displacements are generally smaller, and change rapidly along the trace, with frequent reversals of throw. Near the international boundary horizontal displacements are 15 feet or more, with vertical displacements up to 4 feet. Roads, railroads, fences, and canals are offset by these amounts.

No immediate foreshocks occurred. The previous day an earthquake originated near Twenty-nine Palms. This was felt over a wide area, but because of the desert location of the epicenter no damage resulted. Aftershocks of both this and the Imperial Valley shock continued for several weeks. During this period there were numerous shocks from other sources in southern California. One of these, on June 4, with epicenter southeast of Warner's, damaged the canal system on the west side of Imperial Valley.

A shock of magnitude 6 in northern California on February 8, 1940, was well registered.

Many inquiries received at the Seismological Laboratory indicated that some public alarm was occasioned by an amateur prediction of catastrophic earthquakes to occur between July 20 and August 5, 1940. Needless to say, nothing unusual took place in the indicated interval.

The program of design and construction of new types of seismographic equipment under the direction of Dr. Benioff made favorable progress during the year in spite of considerable diversion of time and energy to national defense problems.

A new short-period galvanometer was developed in collaboration with Mr. Lehner. The coil of this galvanometer is wound directly on the circular mirror. The mirror

has two holes, through which the two suspension ribbons are fastened. Thus the moving system has the lowest possible moment of inertia, with consequent increase in sensitivity.

The three-component film recorder was nearly completed. The unit has a 10-cycle impulse motor drive with stainless steel ribbon belts and pulleys for speed reduction. The optical system is similar to previously described systems except for the reduced dimensions required by the film. It was found desirable to move the galvanometer assembly laterally rather than employ the customary axial motion of the drum.

A number of changes were made in connection with the maintenance and operation of the stations. New storage batteries were installed in the battery room at the Seismological Laboratory. B-battery eliminators with automatic change-over switches were built for all the 10-cycle drives. The Palomar horizontal short-period paper recorder was rebuilt to record both components on one sheet. Tuning-fork drive assemblies and seven moving-coil seismometers were completed for the semipermanent station instruments. The vertical seismometer at Tine-maha was moved to a point 500 feet west of the station and installed under ground. The

vertical seismometers at Mount Wilson and Riverside were also installed under ground in steel tanks. The La Jolla radio receiver was rebuilt for higher sensitivity.

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V. BJERKNES, University of Oslo, Oslo, Norway. *Preparation of a work on the application of the methods of hydrodynamics and thermodynamics to practical meteorology and hydrography*. (For previous reports see Year Books Nos. 5-38.)

Last year's report indicated that the manuscript was about ready for publication. Complete reports are lacking for this year, owing to difficulties of communication with Oslo. Reports for the first few months stated that good progress was being made.

Dr. C. L. Godske was assisting Dr. Bjerknes in completing the manuscript. Dr. E. Höiland was conducting certain experiments in hydrodynamics, the results of which are to be incorporated in the book if completed before publication.

EDWARD L. BOWLES and JACKSON H. COOK, Massachusetts Institute of Technology, Cambridge, Massachusetts. *Research on radio distance measurement*.

In the radio distance measurement project being carried on at the Massachusetts Institute of Technology under the sponsorship of the Carnegie Institution of Washington, apparatus is now being assembled for testing the

feasibility of using amplitude modulated high frequency (200-300 Mc/s) carrier waves for measuring distances ranging from a few hundred meters to some tens of kilometers. Transmitters and receivers are being con-

structed for each of two stations so that a measuring frequency as high as 1 Mc/s can be relayed to and from a remote point and its phase delay in transit determined with some precision at the station of origin. It is planned to adjust the measuring frequency until a simple reference phase relation (0° or 180°) between outgoing and incoming waves is obtained. Measurement of distance will thus resolve itself into measurement of frequency.

An effort is being made to incorporate conventional circuits and circuit elements in the apparatus, in the interest of simplicity and dependability.

It is expected that by the latter part of December 1940 the component parts of this system including the free space link will have been tested. On the outcome of these tests will depend the next steps to be taken in the investigation.

JOSEPH C. BOYCE, Massachusetts Institute of Technology, Cambridge, Massachusetts. *Research in the spectroscopy of the vacuum ultraviolet.* (For previous report see Year Book No. 38.)

This research continued under a grant from the Carnegie Corporation of New York to the Carnegie Institution of Washington.

The program of mapping the spectra of the elements in the vacuum ultraviolet has gone forward, but is still confined to the wave-length range from λ_{2000} to λ_{1200} . In spite of two interruptions to the work, a considerable number of additional spectrograms have been obtained. The parallel Works Progress Administration project for the measurement of the spectra has handled more than half of these spectrograms.

The old pumping system on the Carnegie spectrograph had given increasing trouble, and last autumn it was replaced by a faster system. A self-fractionating pump of 200 liters per second capacity, manufactured by Distillation Products, Inc., was obtained secondhand from another research group at this Institute. It has been mounted with a new large refrigerating trap connecting to the spectrograph. In use it has reduced from two hours to an hour the time required to evacuate the spectrograph. A system has been prepared for the purification and handling of inert gases, particularly to supply helium for use with the hollow-cathode light source.

During the year 72 spectrograms have been made, with various exposure times and with and without wave-length standards, distributed among the following elements: Ti, Fe, Co, Cu, Zr, Ru, Rh, Ag, W, Pt, Au, Th.

The spectrograms are measured on the Harrison automatic comparator. Six runs are made on each exposure, three in each direction. The record films from the comparator are read by W. P. A. workers, and the readings entered on cards and averaged by them. This process has now been completed for 40 exposures, with an average number of about 1000 lines per exposure.

Particular attention has been paid to measurements of iron, copper, and silver. Pressed-powder electrodes of mixtures with one or more of these three elements are used to provide wave-length standards when other elements are under investigation. Measurements are ultimately referred to the iron standards of Green in the region from λ_{2000} to λ_{1550} and to the copper standards of Shenstone at shorter wave lengths. Hollow-cathode exposures with copper, now in progress, will be necessary to tie in our copper lines with Shenstone's standards.

Data on rhodium have been turned over to another member of the laboratory, who is engaged in the analysis of the Rh II spectrum. He reports that a considerable number of lines fit into and extend the term array which had been started on the basis of data from more accessible wave-length regions. Data on ruthenium and thorium are ready for two other local investigators who are working on the spectra of these elements. Data on rare-earth spectra are urgently

needed to complete studies of these elements at longer wave lengths, in progress in this laboratory. The first type of light source tried was not satisfactory for the vacuum ultraviolet, and other methods of exciting these spectra will have to be developed.

A request for the cobalt data has come from Princeton University. Preliminary data on gold have been sent to the University of Michigan. Investigators at the National Bureau of Standards have requested data on three elements not listed above. These elements will be given priority in the coming year. A preliminary report on this program of investigation was made in April at the Washington meeting of the American Physical Society (*Physical Review*, vol. 57, p. 1073, 1940). It was there announced that spectra and wave-length lists would be made available to investigators at other institutions. Contacts have been made with several observatories active in astronomical spectroscopy. The number of laboratories in this country en-

gaged in the analysis of atomic spectra is rather small, but this circumstance helps in the coordination of work. Almost all of these laboratories are represented on the National Research Council Committee on the Line Spectra of the Elements, to which committee Dr. Boyce was recently added.

An article on the general field of spectroscopy in the vacuum ultraviolet has now been completed and will appear in an early number of the *Reviews of Modern Physics*. It includes the critical bibliography of published atomic spectra mentioned in last year's report.

Dr. Lore Misch, research assistant under the grant, resigned on April 1. Her place was taken June 1 by Miss Pauline Pitkin. Mr. N. H. Moore was engaged as a temporary additional assistant for the summer months of 1940.

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F. A. PERRET, Martinique, French West Indies. *Volcanological investigations*. (For previous report see Year Book No. 38.)

Volcanological studies in the British West Indies and in Martinique have continued with aid of a grant from the Carnegie Corporation of New York. After the virtual ending of the crisis at Montserrat and publication by the Institution of a third monograph by Dr. Perret, it was understood that a fourth volume would be forthcoming. This is to be a record of all observations made in the course of forty years of dedication to this work, in the study of many volcanoes in times of the greatest activity, involving two trips around the world. The observations will be classified as to morphology, phenomena, products, etc., instead of being confined to the study of some one event; and the whole will constitute a volume unique in character. It will be a record of actual conditions, personally studied at close range and revealed in quite a special manner by an intensively acquired photographic documentation of every detail.

Field excursions have been made at Martinique for clearing up certain points which always are raised the moment writing is begun, and trips were made to St. Lucia, where investigation is under way regarding the important soufrière, so far most imperfectly studied, and the Pitons, regarding which a new thesis is being developed. A summer visit to New York was necessary, especially as war conditions render photographic work at Martinique impossible. Notes and materials and a great number of negatives are being converted into book material. Most of the writing will be done in Martinique with library facilities at hand, and Dr. Perret expects to return to New York in the spring of 1941 to complete the undertaking. More field work will be needed, and some material from St. Lucia has been examined at the Geophysical Laboratory of the

Institution. In a word, the new book is being made up, with all that this involves, and new knowledge—whose acquisition never ends—is being gained.

In the spring of 1940, Dr. Perret was invited a submit a paper at the Symposium on

Volcanology at the Eighth American Scientific Congress, held in Washington in May. Since he was unable to be present, the paper was kindly read for him by a colleague, who expanded it by references to former observations.

DIVISION OF PLANT BIOLOGY

Central Laboratory located at Stanford University, California

H. A. SPOEHR, *Chairman*

For many years it has been a matter of speculation whether the great multiplicity of substances found in plants arises essentially from a single parent substance which is produced in the photosynthetic process. This multiplicity of substances includes, first of all, the principal groups of foodstuffs, the carbohydrates, fats, and proteins which form the basis of all human nutrition. It also includes the great variety of substances which constitute drugs, rubber, pigments, fibers, and the almost countless array of complicated chemical substances which are found in plants. It has been very generally assumed, and with apparently good reason, that the product of photosynthesis is a carbohydrate, and that all the other organic compounds found in plants are formed from this carbohydrate through the diverse biosynthetic reactions which the plant is capable of carrying out.

That the plant possesses a remarkable capacity for synthesis, probably far greater than that of animals, is a familiar fact and is exemplified by the ability of plants to synthesize their nitrogenous components from simple inorganic compounds. Yet it is of considerable theoretical and practical importance to determine whether the photosynthetic process results in a single compound, of the nature of a carbohydrate, or in a variety of substances of which carbohydrates constitute the dominant or major portion. This cannot be determined through ordinary analytical methods.

It may now, however, be possible to gain some light on this problem by the use of plants which are completely lacking in the normal photosynthetic mechanism; that is, by nourishing such plants artificially with particular organic compounds, and comparing their development with that of their analogues possessing the normal capacity for photosynthesis. Such comparable material is

offered by pure albino maize plants, devoid of chlorophyll and unable to carry out photosynthesis, and the normal green plants which are used as controls.

Because of the fact that the albino plants are incapable of manufacturing their own food by means of photosynthesis, they are able to live only until the food material stored in the seed has been exhausted, and then die of starvation. This is usually a matter of ten to fourteen days after germination of the seeds. During the past year methods have been developed for the artificial nutrition of albino plants which makes it possible to keep such plants alive for at least four months. While there are still many matters of technique to be improved, it is possible to use the method for a study of the organic nutrition of such plants with a view to determining the metabolic changes which particular organic nutrients undergo in the plant.

There are obviously many aspects of the development of plants which must be followed through by this means in order to gain a comprehensive understanding of the metabolic changes which take place. Attention is being given primarily to the nutritional phenomena, although this study will ultimately have to be supplemented by morphological and histological investigations. The rate of development of artificially nourished albino plants is in general parallel to that of normal plants growing in the field; that is, the number of leaves produced is about the same in the two sets of plants. But the total mass of tissue and dry weight which is produced in the artificially nourished plants is considerably less than that in the normal plants. For this reason attention has been given to the ability of the artificially nourished plants to produce the materials constituting the structural elements of the corn plant, more particularly the uronides and pentoses. From the evidence thus far obtained it would appear that the

albino plants are capable of producing these materials from sucrose as the only organic nutrient. The intermediate steps in a bio-synthesis such as the formation of uronides from sucrose will, of course, need further elaboration, and this process is cited here as typical of the metabolic changes which are being followed. The method is applicable to the study of a wide variety of substances, including the vitamins and hormones which have recently been demonstrated to play so important a part in the growth and development of both plants and animals. It is already clear that considerable effort will have to be devoted to the development of special methods of analysis in order to follow quantitatively the production of various materials within the albino plants, and this work is being pushed in several directions as rapidly as possible.

Investigation of the nature of the products formed in photosynthesis is also being pursued from quite another angle. This study has as its objective the following of the carbon dioxide from the atmosphere surrounding the leaf, through the various combinations and transformations it undergoes, to its reduction and elaboration into complex organic matter. Thus far the first steps only in following this course have been taken. Following the course of carbon dioxide as it enters the leaf has been very difficult because the living leaf presents a rather unusual complexity. Not only does the leaf absorb carbon dioxide from the atmosphere during photosynthesis, but it is also constantly producing carbon dioxide within its cells. Consequently it has previously been impossible to distinguish between the carbon dioxide which enters directly into the photosynthetic process from the atmosphere and the carbon dioxide which arises from sources within the leaf.

A means has now been found for "labeling" carbon dioxide through the use of radioactive carbon. By employing radioactive carbon dioxide in the atmosphere surrounding the leaf, it is possible to follow the course of its reactions within the leaf with much greater accuracy than heretofore. Through the co-operation of the staff of the Department of

Terrestrial Magnetism, Dr. J. H. C. Smith has been able to secure radioactive carbon dioxide and carry forward experiments with this material which supplement his earlier studies with ordinary carbon dioxide. Though the experiments have thus far been confined to a single species, it has been possible to demonstrate that in the sunflower leaf the carbon dioxide first enters a kind of reservoir through three types of reaction: solution of the carbon dioxide in the water of the sap, reaction with buffer substances to form bicarbonate ion, and reaction with insoluble carbonates to form soluble bicarbonates. In addition to these primary reactions, a small amount of carbon dioxide is also converted into organic compounds. The significance of this reaction, as well as the nature of the product, has as yet not been established. All these reactions occur in the dark. The fact that the carbon dioxide absorbed in the dark can be converted into organic material by illumination indicates that the absorption of carbon dioxide for use in the photosynthetic process is independent of the photochemical reaction.

Although the use of radioactive carbon dioxide in the investigation of the mechanism of photosynthesis requires the development of new techniques, it is proving to be one of the most useful tools which have yet become available. It is quite possible that if long-life radioactive carbon becomes available for these investigations it may prove to be of even greater usefulness.

One of the greatest lacks in our knowledge of photosynthesis is an understanding of the type of physical-chemical system and some of the essential components which go to make up the photosynthetic apparatus of the plant. It is true that what may be termed the grosser aspects have been determined; we know a good deal about chlorophyll and about the carotenoid pigments, the requisite raw materials; something about the products; and a good deal about how the reaction is affected by various environmental factors which influence the rate of photosynthesis. But because of the extraordinary sensitivity of the photo-

synthetic process, and the remarkable ease with which it is completely stopped by even minor disturbances, we know virtually nothing concerning the more labile parts of the apparatus and the role of the less easily accessible parts of the cell constituents. In the elaborate speculative hypotheses which are being formulated to explain the mechanism of the photosynthetic reaction, a heavy burden is borne by the assumption of elements in the apparatus about which nothing is known. Useful as such hypotheses may be for further investigation, their ultimate value depends upon the definite establishment of the type of physical-chemical system which is involved.

For this reason investigations have been continued on the enzymes which influence the reactions of the pigments and on the state of the pigments in the leaf. That pigments which have been isolated from leaves and subjected to careful study differ in some fundamental aspects from their state in the living plant is now realized. It is difficult to determine the causes for this discrepancy because of the extreme sensitivity of some of the elements of the pigment systems. Some of the changes which the pigments undergo on isolation from the plant are obviously due to destructive oxidative action which is initiated the moment the pigment-containing cells are killed or even injured.

During the past year the mode of action of some of these enzyme systems has been investigated in greater detail. One of the most striking features of such systems is their great specificity, demonstrating that they are dependent upon particular atomic groupings within the molecules affected. To gain an understanding of the chemical reactions which are involved in so complex a mechanism as photosynthesis, it is obviously not sufficient to know the reactions of the individual components as isolated in the pure state. In the leaf the reactions are interrelated and interdependent, and examples have now been found which demonstrate that certain of these processes occur primarily when associated with some other reaction involving materials of a very different nature.

Illustrative of this principle is an investigation which has been carried out to test whether hexenaldehyde is actually the first product, or an early stage, in photosynthesis, as has been proposed by one school of thought. It has been found that this substance, which has been obtained from a large variety of leaves, is actually produced by enzymatic oxidation during the process of extraction and normally exists in the leaf only in very minute amounts, if at all.

The investigations of the photosynthetic efficiencies by Drs. Emerson and Lewis have been considerably extended during the past year, and the results have helped to clarify this much-debated and theoretically important problem. On the basis of an extended series of precise measurements, it now appears highly probable that the high efficiencies which had been previously obtained are subject to serious doubt. This questioning of the correctness of the high efficiencies has resulted from a very critical experimental examination of the methods which are used for these investigations and a scrutiny of the assumptions upon which the computed efficiencies are based. The examination of methods has given indication that the high efficiencies represent results obtained under a rather special set of conditions, and that, although these values are reproducible, they may not give a true measure of photosynthesis.

Measurements of efficiencies have been made with eleven different organisms, representing a fairly diverse group. The values for seven of these fall within a range of about 10 per cent, and the others do not differ greatly. The results show a quantum number of 8 to 12, instead of 4, which was the value obtained from the first careful measurements of efficiency which were made. The significance of the newly determined quantum number lies, of course, in the fact that it indicates that 10 quanta of light energy are used for the production of each molecule of oxygen and presumably for the reduction of each molecule of carbon dioxide to carbohydrate in the photosynthetic process. The

high efficiency represented by the quantum number 4 was particularly attractive from the theoretical viewpoint, because it gave indication that four steps were involved in the reduction of carbon dioxide to carbohydrate, and the sequence of the chemical steps in such a series of reactions could be dealt with on the basis of known chemical principles. A value of 10 quanta permits of so many complications that speculation as to the possible course of the chemical reactions becomes so tremendously involved as to be of little profit.

The establishment of a value for the efficiency of the photosynthetic process is nevertheless of great importance, especially as it has been shown to be a characteristic property of photosynthetic organisms. It has been found to be much less dependent upon culture and experimental conditions than had been supposed. Similarly, the age of the organisms seems to influence the value very little. Although the rate of respiration varies greatly with temperature, this has relatively little effect on the efficiency. It is, therefore, highly probable that further development of the methods for measuring efficiencies will become one of the most useful means of penetrating more deeply into the mechanism of the chemical reactions which are involved in the photosynthetic process.

The investigations in experimental taxonomy deal with the forces that govern the appearance, distribution, and evolution of plants under natural conditions. During the year considerable effort was spent on a study of the local races of which species are composed, and of the genetic systems which characterize species and their regional races.

Species are made up of many intermittent and variable populations, each composed of many biotypes or individual variants. The populations have very little chance for interbreeding, because usually they are separated by some distance geographically. Accordingly, they often become morphologically distinguishable and represent very early stages of evolutionary differentiation within the

species. Populations within major climatic regions tend to become arranged into race complexes of characteristic reaction and appearance, the ecotypes. The number of ecotypes in a species depends in part upon the number of climatic zones it occupies. Differences between ecotypes depend upon series of genes affecting each character, rather than upon single pairs of genes. Some variations within species seem to adapt plants to various kinds of environment, others appear to express only the abundance of possibilities connected with the unfolding of life, but there are no basic differences between these two kinds of variation.

The separation of species by the development of genetic barriers is a secondary phenomenon, which is of great importance for evolution but of no immediate consequence for adaptation. The barriers differ in distinctness, and a dynamic picture of the gradual evolutionary process is obtained through the discovery of barriers between species in various stages of separation. Very strong barriers were discovered, for example, between *Layia heterotricha* and its closest relatives; even its first-generation hybrids were very weak, although the chromosome number of the parents is the same. On the other hand, very slight barriers were observed in the *Madia sativa* complex.

Artificial production of new species through hybridization succeeded in two instances. This was done by the addition of all the chromosomes of both parental species, which were separated by strong genetic barriers.

In the selection experiment a recombination of morphological and reactional characteristics took place. This indicates that genes determine both morphologic and physiologic characteristics of climatic races. This experiment also shows that certain plant groups have latent evolutionary resources which can be released by crossing races from very different climates.

The experiments lead to the concept that environment acts as a sieve that sorts out hereditary forms into suitable ecological

niches by eliminating types not in harmony with it. Genes apparently govern physiologic processes which, in turn, determine a plant's reactions to different environments, as seen in the modifications of the transplant experiments. But how the physiologic processes are related to the environmental modifications on the one hand, and to the heredity of the race on the other, is still entirely unknown.

The desert investigations carried on for the past seven years have been part of a comprehensive program for the botanical study of the entire arid portion of North America. This region embraces four areas with distinctive physical and biological features. The program provides that each of the four shall be investigated separately and the results published independently. Field work has been completed in the Sonoran Desert and the floristic and ecological results are being prepared for publication. In the Chihuahuan Desert field work has been carried on for two seasons, and three more years will be needed to complete the project. The study of the Mojave and Great Basin deserts will require no new work on the flora, which has already been adequately investigated; and the study of their vegetation will be facilitated by the familiarity and accessibility of the two areas. The aims of the work are a complete enumeration of the plants of the North American Desert, an adequate picture of the natural vegetation as modified by geographical and local differences of climate and soil, and a fuller knowledge of the features of structure, function, and environmental relations by which desert plants are marked. From these results it will be possible to learn more of the history of the present plant population of the desert.

Reporting on his cooperative investigations with agricultural agencies, Dr. Clements points out that it is significant of the ecological approach to problems of soil conservation that the main features of the plan should have been brought out by ecological studies. Of much value for forecasting yields

in a particular field, farm, or range is the record of soil moisture, which has already taken much of the hazard out of wheat farming. The first of such records were made in dynamic ecology more than forty years ago. The use of small close trenches to replace pasture furrows and of small subterraces to promote infiltration and control erosion and flooding was recommended some seven years ago and is now becoming standard practice.

The value of tall headed stubble and light subtilage was discovered in the course of studying the natural succession in fields abandoned by the "suitcase farmer" and bids fair to effect the greatest saving of all in soil water. Dr. Clements is of the opinion that the elements of the plan are nearly as essential to the task of regrassing several million acres of repurchased farms as they are to successful crop production. In addition, the specialization of grass covers for the different climates and regions is based in the first instance upon the field studies of climax and succession. Equally important, Dr. Clements believes, is the measurement of adaptability to various regions and sites of more than a hundred species of grasses and legumes and several times as many climatic and edaphic strains. The broad foundation for this has been laid in twelve different habitats at the Alpine Laboratory and an equal number of factor series at Santa Barbara, as a part of the program in adaptation and origin. These methods are now being extended to the main nurseries of the Soil Conservation Service, in large measure under young ecologists trained at the Alpine Laboratory.

With the completion of Dr. R. W. Chaney's study of the Shanwang flora from Shantung Province, China, the Miocene vegetation of eastern Asia may for the first time be effectively compared with that of western North America. A considerable number of species show close relationship, and the dominant genera are essentially the same on both sides of the Pacific. The conclusion is reached that the mild, moist climate which was prevalent in western America during the Miocene also

characterized North China. Distinctive elements in the fossil floras of the two continents suggest that while a land connection may still have existed between them, probably across Bering Strait, there was a climatic barrier at the north which prevented any complete interchange of floras. Intercontinental comparisons of this sort throw much light upon the history of climate, and upon the factors responsible for its change during geologic time.

Continuation of studies of the Tertiary vegetation of Oregon has centered on the Pliocene floras from The Dalles and Troutdale. Additional material has been collected, in cooperation with the Geological Society of America, which indicates a transition from the mild climates of earlier Tertiary time to the more rigorous climate of today. This work in Oregon is closely related to the studies of Dr. Axelrod on the Pliocene of California and Nevada.

Preliminary field work in the area south of the John Day Basin has involved the collection of plant fossils similar to the Mascall flora. Geologic studies indicate that the John Day sequence of volcanic sediments and lavas is found in Harney County, and emphasize the importance of the section in the John Day Basin as a means of interpreting stratigraphy in other parts of western America.

During the past year one of the first projects undertaken by the Carnegie Institution was terminated. The Desert Laboratory has been in continuous operation for thirty-eight years; it may, therefore, be of interest to review the origin and the activities of this project of the Institution very briefly.

The Desert Laboratory was started in 1902 on recommendation of the Advisory Committee on Botany. In the report of this committee, submitted to the Board of Trustees of the Carnegie Institution, it was stated:

There should be established at some point in the desert region of the southwestern United States a laboratory for the study of the life history of plants under desert conditions, with special reference to the absorption, storage, and

transpiration of water. Although there are many botanical laboratories in the humid portions of the temperate regions, as well as several marine laboratories and tropical laboratories devoted in whole or in part to botanical research, a desert botanical laboratory exists nowhere in the world. Yet the phenomena presented in the adaptation of plants to desert conditions are among the most interesting and significant, from an evolutionary point of view, of any in the whole realm of botany.

The economic ground for the establishment of such a laboratory is the enormous development of population and industries that is bound to take place in our arid regions during the next hundred years. The basis of that development is agriculture, both with and without irrigation. At the present time comparatively little is known about the peculiar fundamental processes of plant growth under the unusual conditions surrounding plant life in that region.

During the past thirty-eight years the Desert Laboratory has undertaken extensive investigations of the distribution and functioning of desert plants, the results of which have been set forth in over four hundred journal articles, monographs, and books. Correlative investigations have been made in the desert regions of Algeria, Libya, Australia, and South Africa. The studies of Dr. Forrest Shreve and his collaborators in the desert areas of Baja California, Sonora, and Chihuahua, Mexico constitute a logical culmination of this extensive project, and arrangements have been made for the completion of this work.

It has been the aim of the Desert Laboratory to carry out the work of investigation of desert conditions on as fundamental a basis as possible. The fact that arid and semiarid regions constitute one-third of the earth's land surface and almost one-fourth of the area of continental United States indicates the magnitude of the task. The published results emanating from the Desert Laboratory have contributed materially to a better understanding of the characteristics which are common to all deserts, of the relations between different desert areas, and of the evolution and movements of desert plants. Of importance in this connection has been the study of the climatic

conditions of the desert in relation to the distribution and survival of plant life. The results from the investigations have also contributed materially to an understanding of the problems involved in the formulation of a scientific and rational program of land use.

The scientific problems underlying the use of arid and marginal lands can no longer be considered academic. They are now eminently practical and even urgent. Their importance has been generally recognized, and their study is now being promoted intensively by various tax-supported agencies. The growth of these agencies, as in fact the development of our arid regions, has probably greatly exceeded the expectations of thirty-eight years ago. These agencies are for the most part on a permanent basis, with ample and growing financial support, and definitely committed to a continuing study of the problems of the regions. Many of these problems are also being studied with a view to their practical significance and consequently have become so extensive and inclusive of other branches of science that means far beyond those of the Institution are required.

During the past year the land, buildings,

equipment, and most of the library, constituting the Desert Laboratory, have been donated to the U. S. Forest Service to become the headquarters of the Southwestern Forest and Range Experiment Station. It is believed that the continuing interest of the Forest Service in the type of problem to which the work of the Desert Laboratory has been devoted assures progress in the field in which the Carnegie Institution of Washington made this pioneer effort. The domain of the Laboratory near Tucson, Arizona, consisting of an area of land which has been protected for many years, and which now probably represents a condition of vegetation much like that found by the early Spanish explorers, is of unusual interest and value, and will be perpetuated. This is another instance of the interesting and gratifying relations which the Carnegie Institution of Washington has enjoyed with the U. S. Forest Service.

In conformity with the policy of the Institution to dispose of property which has served its usefulness, and in the interest of economy, the buildings and land constituting the Coastal Laboratory at Carmel, California were sold during the past year.

BIOCHEMICAL INVESTIGATIONS

H. A. Spoehr, J. H. C. Smith, H. H. Strain, and H. W. Milner

THE ORGANIC NUTRITION OF PLANTS

The development of methods for the artificial nutrition of plants has progressed so that it has been possible to keep albino maize plants alive for over four months. This probably does not represent a limit in the length of time the plants can be maintained. Such plants are, of course, completely lacking in the normal photosynthetic mechanism possessed by green plants. After the stored food contained in the seed of the albino plants has been exhausted, they die, unless food material is supplied by artificial means. The rate of development of the plants under such artificial nutritional conditions is not very different from that of normal green plants, which derive their nutrition through the proc-

ess of photosynthesis. Thus the albino plants produced fifteen leaves in a period of 100 to 115 days. Normal green plants, grown in the field from seed from the same ears which produced the albinos, bore on the average the same number of leaves. With the methods for artificial feeding which have thus far been developed, the size which the plants attain is considerably below that of normal plants, running to about 50 cm. in height with a leaf width of 2 to 3 cm.

Various substances have been used as organic nutrients; of these sucrose has given the best results. Contrary to the experience of other investigators with albino plants, it has been found that under the conditions of nutrition followed in these investigations the plants

produce abundant starch in the leaves when fed sucrose. Some organic substances which have been considered sufficient sources of carbon nutrient, as for example glycerine, have proved to be inadequate for the prolonged development of albino maize. It must be emphasized, however, that it is too early to draw definite conclusions regarding the relative value of different compounds for the development of plants which have been deprived of their photosynthetic nutrition. Experiments are also still in progress on the necessity of including various accessory factors such as hormones, in order to attain development approaching that of a normal, photosynthetically active plant. These experiments require rigorous control and analysis.

The albino plants which have been grown with organic nutrients exhibited considerable abnormality in the development of the inflorescences. The pistillate inflorescence developed slowly and with very long silk. Thus far no staminate inflorescences have been observed. Little attention has as yet been given this aspect of the problem of organic nutrition, because the simpler problems of nutrition and growth of the albinos have naturally demanded first attention.

Another method of organic nutrition which has been used depends upon the feeding of green plants kept in the dark. For this purpose sunflower plants have been used chiefly. These are permitted to grow in the light until they have produced six to eight leaves, and are then placed in the dark. Such plants can maintain themselves on stored food material for 10 to 14 days, but then die. When fed with organic nutrients in the dark, the plants have been kept alive for over 2 months. The new leaves and stems produced under these conditions are free of chlorophyll, and the plants grow tremendously in length. Flower buds are developed and these open to the typical yellow flowers, but are entirely lacking in chlorophyll. One of the striking peculiarities of these artificially fed plants is their almost complete lack of pith. There still remain many features of technique to be per-

fected before quantitative and analytical results of value can be expected. But the general method is of sufficient promise to warrant further effort.

One of the objectives in the investigations on the organic nutrition of albino plants was to determine whether pentose sugars and uronides are a product of photosynthesis or whether these substances arise from hexoses in the metabolism of the plant. It has been suggested on purely theoretical grounds that uronides may be the result of oxidation of the terminal carbino group of the hexose units of a polysaccharide. Similarly, the formation of pentoses in plants may arise from this type of progressive oxidation and the subsequent decarboxylation of the uronides. The pentoses and uronides are important constituents of plants and they enter into the composition of a considerable portion of the structural elements. As yet very little is known regarding the mode of formation of these substances, and such theories as have been advanced to account for their formation are based primarily upon speculation and conjecture. In albino maize plants which had been kept alive for three months by feeding sucrose as the only source of carbon, the uronic acid content, as percentage of the dry matter of the leaves, was found to be about twice that in normal plants, grown in the light.

Although many features of the interrelation between food material and the formation of structural elements such as the uronides and pentoses are still to be worked out, the experiments indicate that the latter substances can be formed from sucrose as a primary source of organic nutrition. What chemical transformations the sucrose may undergo in the course of the biosynthesis of the uronides remains to be established. That the albino plants are capable of synthesizing starch from sucrose in the dark has already been mentioned.

There are some indications that under certain conditions starch may be a source of uronic acid formation in the plant through the oxidation of the terminal primary alcohol

groups to carboxyl groups. Leaves of plants which produce an abundance of starch through photosynthesis, such as the sunflower and tobacco, have been found to have a uronic acid content of 7 to 12 per cent of the dry leaf material, though no genetic relation between these two classes of substance has yet been established.

An effort has been made to achieve this type of oxidation of starch *in vitro*. Of the various oxidizing agents tried, the most promising proved to be hydrogen peroxide in the presence of a small amount of ferrous sulphate. It was found to be of considerable advantage to use starch preparations of high solubility. For this purpose starch preparations were used which had been ground extremely fine in a pebble mill with agate marbles for 1500 to 2000 hours. Such preparations of starch when stirred up with 2 to 5 times their weight of cold water yield a clear mucilage which is easily soluble in hot water. Oxidation of such solutions of starch with 2.25 mols hydrogen peroxide per glucose unit yielded, besides small quantities of carbonic, formic, and oxalic acids, two fractions which were insoluble and one which was soluble in ethanol.

The chemical identity of the substances which were obtained in these experiments has not yet been established, and some of the fractions in all probability are mixtures. Analytical results indicate that these products are complex organic acids. As the solubility in alcohol increases, equivalent weights range from 585 to 318, specific rotation from +109° to +53.5°, and respective uronide content from 30 to 55 per cent. These substances reduce Benedict's solution, yield furfural on hydrolysis, and reduce alkaline iodine solution. They are easily destroyed by very mild chemical treatments, such as efforts to hydrolyze them to their simpler component molecules. The investigations are being continued with a view to determining whether these products of the oxidation of starch are true uronic acid compounds or are some modified form of this group of substances.

THE USE OF RADIOACTIVE CARBON DIOXIDE IN PHOTOSYNTHESIS

During the past year advantage has been taken of the availability of radioactive carbon to investigate the chemical mechanism for the absorption of carbon dioxide by unilluminated sunflower leaves and the utilization of this absorbed carbon dioxide in photosynthesis. This work was made possible through the generous cooperation of the Department of Terrestrial Magnetism, whose high-voltage equipment was used for the preparation of the radioactive carbon, and of Mr. D. B. Cowie, Research Fellow of the National Cancer Institute.

In previous experiments it had been found that the amount of carbon dioxide absorbed by unilluminated sunflower leaves could be completely removed by evacuation. This was evidence for the complete reversibility of the process. When, however, these absorption experiments were repeated with radioactive carbon dioxide, it was found that although an amount of carbon dioxide was removed by evacuation which was equal to the amount absorbed, the leaf retained approximately 25 per cent of the radioactive carbon it had absorbed. This observation was interpreted to mean that the carbon dioxide absorbed by the leaf became a part of a carbon dioxide reservoir, and exchanged freely with the carbon dioxide contained therein. By acidification and evacuation all but a small part of the radioactive carbon was removed from the leaves. This was evidence that most of the radioactive carbon retained by the leaves was present as salts of carbonic acid.

Analysis of the data obtained by means of radioactive carbon dioxide has shown that absorption in living sunflower leaves is accomplished: (1) by solution of the carbon dioxide in the water of the sap; (2) by reaction of the carbon dioxide with buffer substances in the sap to form bicarbonate ion; and (3) by reaction with insoluble carbonates to form bicarbonates soluble in the sap of the leaf. From chemical analysis and from the variation in the amounts of radioactive carbon retained after treatment of the leaves with

different partial pressures of carbon dioxide, it has been demonstrated satisfactorily that the insoluble carbonate participating in the absorption is principally calcium carbonate.

In addition to the three types of absorption mentioned, a small amount of radioactive carbon dioxide reacted to form organic compounds. The radioactive carbon so fixed amounted to about 3 per cent of the carbon absorbed from the surrounding atmosphere. The amount fixed did not increase with time, after 15 minutes, but did increase with repeated saturation of the leaf with radioactive carbon dioxide. Killing the leaf by freezing inhibited the reaction. The nature of this radioactive organic material is still obscure. The formation of this material may be without significance to the photosynthetic process, but the fact that leaves produce organic matter from carbon dioxide without exposure to light is important in itself.

The question whether the carbon dioxide absorbed by leaves previous to illumination can be used in photosynthesis was also investigated. Leaves were saturated with radioactive carbon dioxide and then completely removed from the external supply of this gas before being illuminated. After illumination the leaves were tested for radioactive organic material. In every case, such leaves contained about 3 to 10 times more radioactive carbon than the corresponding unilluminated leaves. Leaves were able to photosynthesize this absorbed radioactive carbon dioxide for 30 minutes or more after removal from the external supply of radioactive gas. The greatest amount of utilization occurred when the leaves were illuminated immediately after saturation. This is not surprising in view of the rapid depletion of the internal supply of radioactive carbon dioxide owing to its outward diffusion. From these experiments it was concluded that the absorption of carbon dioxide for use in the photosynthetic process is independent of the photochemical reaction.

The mechanism whereby the carbon dioxide absorbed by the leaf enters the photochemical reaction in photosynthesis is quite unknown. There is no basis as yet for deciding whether it enters as free carbon dioxide,

as bicarbonate ion, or as some organic derivative of carbon dioxide.

The question naturally arises whether the compounds newly formed in photosynthesis are quickly used in respiration. Leaves which had been saturated with radioactive carbon dioxide were illuminated so as to form radioactive organic material. Immediately after illumination these leaves were placed in the dark and the rate of loss of radioactive organic carbon was followed. By this method it was clearly demonstrated that the compounds produced in photosynthesis disappeared quite rapidly. It still remains to be determined how this rate compares with the rate of respiration of known compounds such as glucose.

The radioactive carbon used in these experiments was prepared by bombardment of boron oxide with 2MEV deuterons. About 60 per cent of the radioactive carbon contained in the target at the end of the bombardment was recovered in the form of radioactive carbon dioxide. This radioactive gas was diluted about 10^{14} times with ordinary carbon dioxide to make it suitable for use. A method was developed for the quantitative determination of the radioactivities of the various samples encountered in this investigation. The apparatus consisted of a Lutz-Edelmann electrometer connected to an ionization chamber, under which the sample to be measured was placed in a specified position. Samples of radioactive carbon dioxide were dissolved in potassium hydroxide solution prior to measurement. The radioactive decay of the various samples was corrected for by means of the half-life constant of C¹¹, 20.35 minutes. This value was determined as the average of several measurements and is probably accurate to ± 0.08 minute.

Unilluminated nettle leaves, like sunflower leaves, absorb relatively large quantities of carbon dioxide. For this reason a comparison of the two absorption systems has been undertaken. The results obtained thus far indicate that the two systems are similar: that in both, carbon dioxide is absorbed by the water of the leaf, by buffers contained within the sap of the leaf, and by insoluble carbonates.

OXIDATION-REDUCTION REACTIONS IN KILLED LEAVES

Investigations of the labile chemical systems that are believed to form a part of the photosynthetic mechanism of green plants have revealed a complex interrelation among many reactions. This is particularly true of the oxidative processes that occur when leaves are killed under conditions that are not destructive to enzymes.

If leaves of young plants or of etiolated seedlings are killed with anesthetics, by grinding, or by freezing and thawing, a great many of the constituents of the plastids, such as ascorbic acid and the carotenoid pigments, are destroyed through oxidation. In the case of clover leaves, a portion of the oxidized ascorbic acid is reduced again when the killed leaves are placed in vacuum. With leaves of several other plants tested, only traces of ascorbic acid are regenerated in the absence of oxygen. In all these plants, carotenoids destroyed through oxidation are not re-formed in vacuum or in the presence of ascorbic acid. An excess of ascorbic acid does not reduce the carotenoids contained in living or in killed sections of carrots and of etiolated leaves.

Oxidation of ascorbic acid in killed leaves appears to be catalyzed by an enzyme, the nature of which has not been determined. This enzyme system is not expressable with the juice from whole killed leaves, and it is not extractable with water from freshly ground barley leaves. The capacity of killed leaves to oxidize ascorbic acid is destroyed by cyanides and by strong solutions of urea. It is not altered by dilute solutions of urea or glycerine. Enzyme inactivated by urea or cyanide is not restored through removal of these compounds by dialysis. Although the ascorbic acid oxidase system is very resistant to drying, it is rapidly inactivated when fresh leaves are heated.

In last year's report, it was pointed out that the oxidation of carotenoid pigments in killed leaves is apparently dependent upon oxidation of ascorbic acid or other compounds. It has since been found that in some plant materials

oxidation of carotenoids is coupled with an oxidation of unsaturated fats.

Other investigators have found in soy beans an enzyme that accelerates the addition of atmospheric oxygen to carotenoid pigments dissolved in unsaturated fats. Extracts of white lupine seeds have also been found to increase the oxidation rate of several fats. Further investigation of these reactions has now demonstrated that this enzyme, which occurs in both the green and the mature seeds of most legumes, is a highly specific catalyst for the addition of oxygen to certain unsaturated fats and fatty acids. Only those compounds that contain the

$\begin{array}{c} \text{H} & \text{H} \\ | & | \\ -\text{C}=\text{C}(\text{CH}_2)_7\text{C}(\text{O})- \end{array}$

group are attacked by the enzyme and oxygen. Such compounds were either oleic, ricinoleic, eleostearic, linoleic, and linolenic acids or their esters or amides. Compounds with even minor structural differences, as elaidic acid, the trans-isomer of oleic acid, oleyl alcohol, the reduced carboxyl derivative of oleic acid, and erucic acid, with 11 instead of the usual 7 carbon atoms between the ethylene group and the carboxyl group, were not oxidized. However, these three compounds did not prevent the addition of oxygen to oleic acid by the enzyme.

Study of the oxidation of carotenoid pigments by the enzyme from legumes revealed that these pigments are not oxidized directly. The reaction depends upon simultaneous oxidation of the unsaturated fats. Carotenoids dissolved in saturated fats or in unsaturated compounds that are not oxidized by the enzyme are also unattacked by the enzyme and oxygen. Carotenoids, dissolved in unsaturated fats that had been partially oxidized but from which the enzyme had been removed, were not oxidized.

Substances other than the carotenoids are also oxidized when dissolved in unsaturated fats and treated with the enzyme from legumes. Of special interest in this connection is the oxidation of the green chlorophylls to colorless products.

The rate of oxidation of carotenoids by the legume enzyme and unsaturated fats depends

upon the autoxidizability of the pigments themselves. Zeaxanthin, the most stable of the leaf xanthophylls, is oxidized more slowly than the other leaf carotenoids. Eschscholtz-xanthin, the least stable of the known xanthophylls, is oxidized most rapidly.

Thus far it has been impossible to prove that leaves contain the same oxidative enzyme found in seeds of legumes. It is of significance, however, that, in many respects, the oxidative properties of killed leaves resemble those of the legume seeds. Extracts of older green leaves inhibit oxidation of fats and dissolved carotenoids by the enzyme from legumes. This inhibition of the oxidation of the yellow pigments is similar to that observed in leaves themselves several years ago.

Preparation from plants of an enzyme that catalyzes addition of oxygen to the carbon atoms of double bonds throws a new light on the mechanism of respiration or oxidative metabolism. It now appears that respiration may involve direct addition of oxygen to carbon atoms as well as oxidation through removal of hydrogen by so-called hydrogen carriers or acceptors.

Oxidation of the carotenoids by the enzyme from legumes and by leaves depends upon the state or physical condition of the pigments. For example, if carotenoids are dispersed as a colloidal solution in water before treatment with enzyme and fat, little or no oxidation of the pigments takes place. These results as well as observations recorded in the following section of this report point to the importance of knowledge concerning the state and distribution of pigments in leaves to an interpretation of their function.

Destruction through oxidation of the tannins contained in some leaves presents many baffling problems. The enzyme system most likely to catalyze oxidation of these compounds is cytochrome and its oxidase. As yet, the usual spectrometric methods for detection of reduced cytochrome have failed to reveal its presence in these leaves. Whether or not all leaves contain this or another similar system remains to be established.

When leaves are killed in the presence of

thiobarbituric acid and air, there is formed a red compound that exhibits selective absorption of light of wave length 531 m μ . This same colored compound may be formed by treating a number of compounds of diverse chemical structures with hydrogen peroxide for several days, then adding thiobarbituric acid after the excess of hydrogen peroxide has been decomposed with manganese dioxide. Presumably the formation of the colored compound in plants follows an analogous course.

THE STATE OF PIGMENTS IN LEAVES

Yellow and green pigments as they are found in leaves and in extracts formed by grinding leaves with water exhibit spectral absorption properties that are slightly different from those of the same pigments dissolved in the common organic solvents. In the aqueous extracts, the pigments appear to be associated with protein, and as a consequence, it has been assumed that the unique spectral properties of the pigments in the leaf are the result of a chemical union between the protein and the pigments.

Investigations carried on during the past year have shown, however, that it is possible to prepare dispersions of chlorophyll in water which exhibit all the spectral properties displayed by chlorophyll in the leaf, without a trace of protein present. If a protein, like albumen, is added to such a chlorophyll preparation, the pigment particles associate themselves with the protein particles and can be precipitated with them, but there is no further change in the spectral properties of the mixture. If tannic acid is added to these protein-colloidal chlorophyll mixtures, the pigment is precipitated with the protein. A similar phenomenon is encountered in grinding leaves that contain tannins. As yet it is not known whether the mixtures of pigments and proteins obtained by grinding leaves are normal constituents of the living leaf or are artifacts. Information obtained so far does not support the postulations that, in the leaf, chlorophyll is associated in large units containing as many as 3000 molecules, and that all these molecules are associated with protein.

THE ORIGIN OF HEXENALDEHYDE OBTAINED FROM LEAVES

It has been known for some years that many species of leaves yield hexenaldehyde, hexen-(2)-al(1), up to 0.02 per cent of the fresh weight of the leaves. Some years ago histological evidence was advanced to the effect that the aldehyde was localized in or about the chloroplasts. This, together with the fact that the content of hexenaldehyde in leaves seemed to be influenced positively by illumination, and the obvious similarity in chemical structure between hexenaldehyde and the hexose sugars, served to build a hypothesis that this aldehyde represented the first or an early step in the photosynthetic process. An investigation has been carried out by Mr. William Nye to determine the role, if any, that this leaf aldehyde plays in photosynthesis.

The experiments demonstrate that the amount of hexenaldehyde obtained from leaves is influenced more by factors involved in the isolation process than by the periods of illumination or darkness to which the leaves are exposed. The isolation procedure consists of steam distillation of ground leaf material, and the precipitation of the hexenaldehyde in the distillate by means of 3-nitrobenzhydrazide. The experimental evidence now obtained points to the conclusion that the aldehyde is formed during the process of grinding. Leaves which had been killed with hot water, toluene, or chloroform before grinding yielded little or no aldehyde, nor was aldehyde obtained by the distillation of whole leaves.

When leaves are ground in a ball mill in an atmosphere of air or oxygen, there is a decrease in pressure in the ball mill, and the aldehyde can be obtained upon distillation of the ground mass with steam. When, on the other hand, leaves are ground in an inert atmosphere such as nitrogen or carbon dioxide, the pressure remains the same, or increases, and no aldehyde is obtained on distillation. The influence of grinding on the production of the aldehyde was demonstrated in a number of ways. It is primarily the

grinding of the living leaf tissue in contact with oxygen which is responsible for the production of the aldehyde. For example, much more aldehyde is obtained from leaves ground in nitrogen, cold water added, then ground in oxygen and distilled, than from leaves ground in nitrogen, boiling water added, then ground in oxygen and distilled.

The experiments also demonstrate that the leaf aldehyde is, for the most part, a result of injury in the presence of oxygen, and that it is formed by some enzymatic oxidation process. In an effort to determine the substrate which is oxidized, small amounts of ethyl, n-butyl, n-hexyl, and benzyl alcohols were added to leaves before grinding. None of these alcohols gave evidence of being oxidized to the corresponding aldehydes by this system. The yield of hexenaldehyde was increased by the addition of oleic acid and of benzyl alcohol, and this is due apparently to the presence of peroxides in these substances. That a type of coupled oxidation may be involved in the formation of the hexenaldehyde is indicated by the fact that antioxidants such as pyrogallol distinctly inhibit the formation of the aldehyde. Ten different species of leaves were examined in this investigation. The leaves of *Ailanthus glandulosa* proved to be the most satisfactory, because its long compound leaves permitted the preparation of large duplicate samples by the half-leaf method.

In order to confirm the chemical structure which has been ascribed to the leaf aldehyde obtained from these plants, hexene-(2)-al-(1) was synthesized in the laboratory. This aldehyde formed a m-nitrobenzhydrazide which was identical with that obtained from the leaf aldehyde. It is highly probable that the leaf aldehyde represents an intermediate oxidation product, resulting from enzymatic oxidation of the corresponding hexene alcohol. This oxidation may be carried beyond the aldehyde stage if the ground fresh leaf material is permitted to remain in contact with air for longer periods of time. It is highly probable that this accounts for the variable yields of hexenaldehyde which were obtained, as the aldehyde

must thus be considered an intermediate product of the oxidation of the alcohol to the corresponding acid.

The results from this investigation constitute further evidence of the great lability of many of the constituents of living cells, and of the ease with which these constituents undergo oxidative change when the cells are killed. Conclusions concerning the chemistry of organisms can for the most part be drawn only from data of chemical analysis of such

organisms or of particular tissues. Yet such analyses usually involve the killing of the cells. As has been pointed out in previous reports, many cell constituents undergo drastic changes the moment the cells are killed. This leads to the destruction of many physiologically important constituents, and, as in the case just discussed, to the formation of substances which are not constituents of the living organism or are contained therein in only very small amounts.

THE QUANTUM EFFICIENCY OF PHOTOSYNTHESIS

Robert Emerson and Charlton M. Lewis

It was stated in last year's report that the high photosynthetic efficiencies found by Warburg and Negelein, and confirmed by Rieke, were dependent on a certain combination of conditions of culturing the cells and carrying out the measurements of photosynthesis. Still higher efficiencies were obtained by further adjustment of conditions. The highest values verged upon being inconsistent with thermodynamic requirements. There were other reasons as well for questioning the reliability of certain of the assumptions upon which the computed efficiencies were based. These assumptions related to the measurement and calculation of the rate of photosynthesis. The procedure of Warburg and Negelein had been followed because the initial objective was the confirmation or rejection of their results. These workers assumed that for each mol of oxygen produced by assimilating cells, one mol of carbon dioxide was absorbed. Several tests of this assumption were made during the fall of 1939. The results showed that during prolonged periods of light or darkness the ratio of exchange of oxygen and carbon dioxide may approach a value close to unity, but that during the short periods of light and darkness used for measuring efficiency this ratio may be far from unity, and may be subject to sudden fluctuations. During the first moments of illumination following a dark period, there is regularly less carbon dioxide absorbed than oxygen produced. With light intensities slightly higher than

those customarily used for measuring efficiency, the deficit in absorption of carbon dioxide becomes a positive evolution of carbon dioxide. During the dark period following a light exposure, when respiration is measured, less carbon dioxide is produced than the amount of oxygen consumed. Thus one of the fundamental assumptions upon which the photosynthesis measurements had been based proved to be incorrect. When photosynthesis is calculated from observed pressure changes on the basis of an assumed equality of exchange of oxygen and carbon dioxide, the changing ratio of exchange results in a computed rate of photosynthesis considerably higher than the true rate. The very high efficiencies reported last year resulted from this misinterpretation of the measurements.

Though it is not possible to state with certainty that Warburg and Negelein's efficiencies were subject to the same error, nevertheless a number of details of their observations are in such close agreement with our own, and are so readily interpreted on this basis, that it seems more than likely that their high efficiencies resulted from the same misinterpretation of data. In the case of Rieke's measurements, data are included which make a more direct comparison with our own results possible. Here it is clear that his high efficiencies resulted from the same error which was involved in our own.

Before reporting further work on the quan-

tum efficiency, it is appropriate to mention some of our observations on the carbon dioxide exchange which proved so disturbing to the earlier efficiency measurements. The cells appear to contain a system which exchanges carbon dioxide in a manner not reconcilable with the usual concept of respiration and photosynthesis. Though this system may play no direct part in either respiration or photosynthesis, its potential importance for plant physiology should not be overlooked. It may also prove to be related to other aspects of carbon dioxide absorption by leaves being investigated in this Division.

The irregularities in the carbon dioxide exchange in both light and darkness are dependent on the continued physiological activity of the cells. Boiled cells do not show these responses. Concentrations of phenyl urethane sufficient to inhibit photosynthesis also inhibit carbon dioxide evolution in response to illumination. This carbon dioxide evolution seems to depend on oxygen respiration during the preceding dark period. If only a limited amount of oxygen has been available, so that it is quickly consumed in the dark and aerobic respiration ceases, then there will be a correspondingly limited production of carbon dioxide upon illumination. If no oxygen is available during the dark period, then illumination will produce no carbon dioxide. Respiration in the dark must continue for a period of about one hour in order to produce a maximum evolution of carbon dioxide in a subsequent light exposure. If the dark period follows an exposure to strong light, the carbon dioxide production is at first much less than the consumption of oxygen in respiration, but gradually increases until the two become nearly equal. Up to this time there has been a deficit of carbon dioxide production, the magnitude of which can be calculated on the assumption that oxygen and carbon dioxide are exchanged in equal amounts in the respiratory process, and that the carbon dioxide which failed to appear was stored in some reservoir inside the cells. Now when the light is turned on, oxygen consumption due to respiration gives way

to oxygen production due to photosynthesis, and at the same time there is a great increase in carbon dioxide production, as if the reservoir filled during the dark period were suddenly being emptied. This unexpected carbon dioxide production gives way after a few minutes to a small but slowly increasing carbon dioxide absorption, which in time becomes equal to the oxygen production. There has now been a net deficit of carbon dioxide absorption, and its size may be calculated on the same assumption made for the dark period, namely, that oxygen and carbon dioxide have really been exchanged in equal amounts, this time in photosynthesis instead of respiration, and that the deficit in carbon dioxide absorption is due to the emptying of the reservoir which was slowly filled during the preceding dark period. Both of these calculations are necessarily inexact because the return to equality of gas exchange in both light and darkness is approached asymptotically. But the agreement of the figures for carbon dioxide absorption in darkness and evolution in light lends support to the assumptions made, and to the idea of a reservoir. The emptying of the reservoir in the light causes a much more striking disturbance in pressure change than its filling in the dark, because the former is nearly completed during the first two minutes of illumination. The filling in the dark starts less rapidly, and does not exceed the rate of carbon dioxide production due to respiration. There is no sudden reduction of pressure in the dark comparable with the burst of pressure on illumination.

If the carbon dioxide reservoir has been filled during a long period of darkness, the degree to which it can be emptied by light depends on the intensity used. If a low intensity is used first, and the reservoir partially emptied, then a higher intensity will produce a further evolution of carbon dioxide, up to the point where the reservoir is completely emptied. There is evidence that this is accomplished with light intensities far below that required to saturate photosynthesis. This may be one reason why the phenomenon has

generally been overlooked. In experiments on the maximum rate of photosynthesis, the photosynthesis itself is so rapid as to obscure the existence of the reservoir. But maximum efficiency of photosynthesis prevails at slower rates, and at light intensities where the reservoir plays a prominent part in the gas exchange.

The experiments reported here were done with sodium light. There is evidence that the wave length, as well as the light intensity, may be a determining factor in the emptying of the reservoir.

The amount of carbon dioxide absorbed in the dark, and the amount produced in light of optimum intensity, depend on the partial pressure. At the carbon dioxide concentration of ordinary air, the existence of the reservoir is scarcely detectable. It becomes noticeable, though still very small, at about 0.5 per cent carbon dioxide. At 5 per cent, the concentration formerly used for efficiency measurements, the filling and emptying of the reservoir are prominent, and cause rates of pressure change more rapid than those caused by respiration. The effects are somewhat larger at 12 per cent.

These pressure disturbances can result in errors in the photosynthesis measurements in two ways. Both their magnitude and their distribution in time can play important parts. A number of factors were formerly found to be significant in producing high efficiencies by the method of Warburg and Negelein, but have since been shown to play no part in the efficiency as determined by present methods. It may be inferred that such factors increased the prominence of the pressure changes caused by the carbon dioxide reservoir, but separate experiments to show whether the effect was due to the size of the pressures or to their distribution in time have not been made. Factors in this class are the temperature of measurement, 10° C. giving maximum effect; an abundance of microelements in the culture medium; and a low light intensity for culturing the cells, combined with a reduction in intensity shortly before harvesting the cells.

To avoid errors introduced by the carbon dioxide reservoir, oxygen exchange alone has

been used as a measure of photosynthesis. Efficiency measurements are now made with cells suspended in a carbonate-bicarbonate buffer mixture which maintains a constant partial pressure of carbon dioxide. The rate of oxygen exchange comes quickly to equilibrium after each change of conditions, and the computed rate of photosynthesis is independent of the time periods chosen for light and darkness. Assuming that oxygen production is a measure of carbohydrate synthesis from carbonic acid, the maximum efficiency of *Chlorella pyrenoidosa* in the region of the yellow sodium line is about 25 per cent, instead of about 50 per cent as reported by Warburg and Negelein.

The measurements will gain much in significance if a given efficiency can be shown to be characteristic of the photosynthetic process in general, rather than being limited to a relatively unimportant organism which happens to be suited to the precise methods required for efficiency measurements. The accompanying table shows that values in close

Organism	Quantum yield at about 1200 ergs/cm. ² /sec.
<i>Chlorella pyrenoidosa</i>	0.101
<i>Chlorella vulgaris</i>	0.092
<i>Chlorococcus</i> sp.	0.104
<i>Eudorina</i> sp.	0.095
<i>Stichococcus bacillaris</i>	0.107
<i>Scenedesmus</i> D ¹	0.094
<i>Scenedesmus</i> D ³	0.100
<i>Gyrodissia humicola</i>	0.090
<i>Oocystis naegeli</i>	0.096
<i>Chroococcus</i> sp.	0.086
<i>Wolfiella lingulata</i>	0.060

agreement have been obtained for a fairly diverse group of organisms. Efficiencies are expressed as quantum yields, the significance of which is discussed below. Seven of the values fall within a range of about 10 per cent, and the others are not far off. Nine different species of green algae are included, as well as one blue-green alga, a species of *Chroococcus*. This is a member of the Myxophyceae, probably related to the molds, and perhaps representing a more primitive type of alga. It has the additional interest of a very different pigment complex. A tentative

value is also included for the small aquatic flowering plant *Wolffiella*. Our method of measurement is not as well adapted to the study of this organism as it is to the algae, and the efficiency figure lacks precision. It is nevertheless interesting that a flowering plant can show a photosynthetic efficiency of the same order of magnitude as those of the various algae studied. The collected results suggest that the efficiency measurements made with *Chlorella* may become a basis for more general considerations concerning the nature of the photosynthetic process.

The efficiency of *Chlorella pyrenoidosa* has been studied in more detail, and every effort has been made to find conditions which would lead to higher values. But the maximum efficiency seems to be far less dependent upon cultural and experimental conditions than had previously been supposed. Factors mentioned last year as influencing the efficiency measured by the method of Warburg and Negelein are largely without effect on the efficiency measured by oxygen production. Cells may be grown over a wide range of light intensities, and show the same efficiency. The age of the culture is of no importance within wide limits, provided an abundance of microelements is present initially. Shortage of microelements in the culture medium results in diminished efficiency. In maintaining or restoring the maximum value, the element manganese plays a major part. Under some circumstances it may have an effect within a short period after it is supplied.

The efficiency is relatively independent of the temperature. Measurements made at 0°, 10°, and 20° C. give values in close agreement. This is of particular interest because of the great difference in rate of respiration over this range of temperatures. The respiration enters as a correction to every photosynthesis measurement. As yet there is no method of measuring respiration simultaneously with photosynthesis, so the rate is measured immediately before and after each light exposure. It is assumed that this rate is a close approximation to the rate prevailing during the light exposure. Were this not so, one would hardly expect such close agree-

ment in efficiency over a temperature range from 0° to 20°.

Respiration may be varied in other ways without altering the efficiency. Cells grown at high light intensity may have a rate of respiration 2 or 3 times that of cells grown at a lower intensity, and yet show the same quantum yield.

An efficiency of 25 per cent in sodium light is equivalent to a quantum yield of about 0.12, or a quantum number of about 8 (see accompanying table). This is in good agree-

Different ways of expressing efficiency

Per cent (for sodium light, $\lambda = 589 \text{ mm.}$)	Quantum yield	Quantum number
28.5	0.125	8
25.4	0.111	9
22.8	0.100	10
20.8	0.091	11
19.0	0.083	12
17.6	0.077	13
16.3	0.072	14
15.2	0.067	15

ment with results obtained by the group working on photosynthesis at the University of Wisconsin, where several other methods of measurement have been used. A quantum number of 8 means that eight quanta must be absorbed for each molecule of oxygen produced in photosynthesis, and presumably for each carbon dioxide molecule reduced to carbohydrate. Whereas Warburg and Negelein's quantum number of 4 indicated an astonishing efficiency, quite out of line with that of other physiological processes, 8 provides sufficient energy so that photosynthesis becomes more readily conceivable in terms of the known principles of chemical thermodynamics. But the rejection of the number 4 in favor of a higher figure reduces the value of speculation as to the sequence of chemical steps by which the plant produces carbohydrate from carbonic acid. If the quantum number is used as a guide to the number of photochemical steps involved, a value of 8 permits so many different reaction combinations as to render speculation along these lines almost fruitless at the present stage of knowledge.

Having rejected Warburg and Negelein's value for photosynthetic efficiency because of the method of measurement, we must also question their results on the dependence of efficiency upon wave length. It is therefore more than ever essential to carry out efficiency measurements at different wave lengths, using improved methods. During

the past year, good progress has been made on the construction of a monochromator for this purpose. Generous cooperation has been received from members of the staff of the Mount Wilson Observatory. It is hoped that the rest of this year will be devoted largely to a study of the dependence of efficiency on wave length.

INVESTIGATIONS ON THE CAMBIIUM AND ITS DERIVATIVE TISSUES

I. W. Bailey

The major objectives of these investigations and their significance in the consideration of certain physiological, biochemical, and biophysical problems have been outlined in previous Year Books, Nos. 32 to 38. There are other aspects of the work which bear upon problems in the fields of taxonomy and paleobotany. Extensive investigations of the stems of a wide range of representative angiosperms have demonstrated statistically that there are clearly defined trends of structural specialization in the conducting tissues of the xylem. Certain of these trends of evolutionary modification are irreversible and are more or less closely synchronized with concomitant changes in the storage parenchyma and

cambium. They are, therefore, significant in any general discussion of the phylogeny, relationships, and classification of the angiosperms. It has seemed advisable in this connection to institute an intensive study of some particular family of the dicotyledons and to determine to what extent the structural modifications of the cauline cambium and xylem are correlated with evolutionary specializations in other organs and tissues. During the past year, therefore, attention has been focused upon the task of assembling adequate material of the pantropical family Icacinaeae as a basis for such an investigation, and of preparing stems, nodes, leaves, flowers, and pollen for detailed microscopic investigation.

EXPERIMENTAL TAXONOMY

Jens Clausen, David D. Keck, and William M. Hiesey

The investigations in this field, dealing with the forces that govern the appearance, distribution, and evolution of plants under natural conditions, are progressing along several fronts. The governing factors are closely interwoven and must be considered together. Such investigations must also employ various groups of plants, for life exists in so many patterns that a one-sided approach is apt to result in incomplete or even misleading interpretations. Practical considerations, however, make it imperative to concentrate effort on problems of highest strategic importance, advancing first in one direction, then in another, according to a predetermined plan, and finally coordinating the results.

During the current year, attention has again been turned toward a study of the genetic systems which characterize species and their regional races. This has followed a period of concentrated study on the ecological differentiation in complexes of perennial species as expressed in the reactions of their component races to contrasting environments (see Carnegie Institution of Washington Publication No. 520, *Experimental studies on the nature of species. I. Effect of varied environments on western North American plants*).

Our studies on the genetic basis of species have focused mainly on the annual tarweeds (Madiinae). Work on these plants was begun

from a taxonomic viewpoint by the late Dr. H. M. Hall, and entered its genetic phase in 1932. Members of this subtribe of Compositae have proved to be particularly desirable subjects for experimental study because they show an exceptionally complete array of relationships and a great variety of evolutionary patterns. So much information has been obtained on the general problem of the nature of species from the Madiinae as a whole that it was found desirable to concentrate the experimental work during 1940 on *Layia* and *Madia*. The account of these genera will be brought to publication as soon as the data on hand have been fully analyzed. Then the garden studies on *Hemizonia*, *Holocarpha*, and *Calycadenia*, already far advanced, will be completed and a companion account published.

THE ORGANIZATION OF PLANT GROUPS

On the background of the best set of data on *Layia* and *Madia* so far obtained, together with those from previous years, we can now visualize with increasing clarity the composition and interrelations of species in these genera. Nearly every one of the more widely distributed species is composed of large numbers of local populations. These are geographically discontinuous, often separated by many miles, and there is slight chance for interbreeding between them. Within the population, however, there is free interbreeding. Accordingly, each population, in spite of considerable individual variation within it, has developed into a morphological-geographical unit more or less distinguishable from the others. Such local populations, therefore, often satisfy the morphological and geographical requirements for specific distinction, but they fail to satisfy the genetic requirement, because they interbreed freely when given a chance. They represent very early stages of differentiation within species and are of interest to students of evolution, but have no taxonomic standing.

Of different rank are the regional race complexes, or ecotypes, developed in certain climates. For example, wherever *Layia platy-*

glossa touches the coast, late-flowering races have evolved with succulent herbage, short, prostrate stems, and thirteen rather than eight ray florets. These characteristics are heritable, and the prostrate habit may even become accentuated in the experiment garden, where competition is eliminated. Unrelated species have developed strikingly parallel races in the maritime environment. The maritime populations of a species can be recognized as composing a maritime ecotype because of their similarity in certain characteristics. In other characteristics, however, the maritime vary as much as the inland populations. The characters that vary are presumably of no importance for survival in the maritime environment.

A different sort of ecotype has evolved in genera that have forms which flower in different seasons. Such are the spring-flowering and fall-flowering ecotypes of species like *Madia elegans*, the *M. sativa* complex, *Hemizonia luzulaefolia* and *H. multicaulis* of *Euhemizonia*, and one of the *Holocarpha* species. In general the spring-flowering or vernal ecotypes are shorter, less glandular, and branched farther down, and have different kinds of leaves from the autumnal ecotypes of the same species. They finish flowering before the fall ecotypes commence to bloom. The two may grow close together in the wild, but because of their separation in time of development they have very little opportunity for crossing under natural conditions. Their artificial hybrids are fertile, however, and the vigorous second generation shows a remarkable recombination of parental characters in earliness and habit.

The Madiinae occupy mainly the zones from the coast to the Sierran foothills. As a consequence they have developed but few ecotypes. In contrast, most of the perennial species complexes employed in the transplant investigations extend from the coast to the rugged alpine regions of the Sierras and even eastward into the arid Great Basin, with an increase in the number of ecotypes corresponding to the number of major climatic zones they occupy.

Without exception it has been found that

differences between ecotypes depend upon series of genes affecting each character, rather than upon single pairs of genes. This raises a question in regard to the maritime ecotypes: Did these originate only once, subsequently spreading along the coast, or did their disconnected populations along this narrow belt arise independently, each from the nearest inland race?

In order to throw light on this question, two races of the maritime ecotype of *Layia platyglossa* were crossed. These races are separated in nature by a distance of 150 miles, one north of, the other south of San Francisco Bay. It was found that all of some 2500 second-generation offspring were distinctly maritime, that is, late and prostrate, with short internodes and thirteen rays. This lack of segregation indicates that the genes responsible for the maritime characteristics were identical in the parents and located in homologous chromosomes. Otherwise, early or erect types should have been segregated. This result can be explained most simply by assuming that the two races are of the same origin and have crossed the barrier of the Golden Gate, rather than that long series of identical mutations occurred in different localities.

In the Madiinae, then, the more widespread species consist of many intermittent and variable populations, each composed of many biotypes or individual variants. The populations within major climatic regions tend to form complexes of characteristic reaction and appearance, the ecotypes. But the genes that determine the great morphological and physiological variation within populations and ecotypes of one species are of such a nature and so arranged that they can be freely interchanged without detriment to the offspring.

Considerable time was spent in investigating the genetic barriers between approximately twenty-five species. There are all kinds and grades of barriers, delimiting species in all stages of differentiation and evolution, as one would expect in a dynamic, changing world. Any one of many evolutionary avenues may lead to effective genetic separation of species,

but not all result in equal morphological distinctness.

Layia and the sections *Euhemizonia* and *Centromadia* of *Hemizonia* are characterized by species complexes consisting of genetically closely related, although morphologically and ecologically quite distinct, species. These differ by many genes, but their hybrids are relatively fertile (2 to 20 per cent). *Madia*, *Calycadenia*, and the section *Deinandra* of *Hemizonia*, on the other hand, consist mainly of well isolated single species, separated by strong sterility barriers.

Within *Madia* two complex groups have received special study. One is the 8-chromosome *Madia elegans*, composed of three or four major ecotypes, each consisting of many variable populations. From new evidence it appears possible that *Madia Wheeleri* is only an ecotype of *Madia elegans*, although prior to these investigations it was considered to belong in the genus *Hemizonia*. The other group is the extremely variable, 16-chromosome *Madia sativa* complex, including *M. sativa*, *gracilis*, *anomala*, and *capitata*, and *M. chilensis* from Chile. Only the last named appears separated from the others by a fairly strong genetic barrier. The other four are composed of many individually distinct but variable populations. There are definite trends toward the development of geographical and seasonal types which are morphologically recognizable, but the internal barriers separating them appear to be too indistinct to warrant their further consideration as species. Discovery of imperfect barriers and the occasional production of spontaneous hybrids in this otherwise self-pollinating group makes its complexity and the occurrence of many intermediate forms more understandable. But in this group fairly well-defined ecotypes can be recognized, and barriers are developing that may lead to future speciation.

Not only do species differ in size, content, and distinctness, but they may either be grouped into complexes or be completely isolated, depending upon the distinctness of the barriers between them. So one finds the living world to be organized into recognizable units of higher and higher order. The organ-

ization is more or less discontinuous, but the discontinuities are of different rank. The smallest unit above the individual is the population, and the largest unit that one can hope to analyze experimentally is the species complex or cenospecies.

MADIINAE HYBRIDS

In addition to the natural races, many hybrid combinations of *Layia* and *Madia* were grown in the Stanford garden in 1940. These cultures yielded critical data relating to the delimitation of species, to their relationships, and to their evolutionary background. At this time attention is called to only a few of the more remarkable hybrids.

Madia sativa ($n=16$) \times *Layia platyglossa* ($n=7$): This was a natural hybrid found in a culture grown from seed collected near Muir Beach, north of San Francisco. Both parental strains from the same locality were grown this year, and the hybrid was discovered in the culture of *Madia sativa*. It increases to three the known intergeneric hybrids within the Madiinae (see Year Book No. 36 [1936-1937], p. 212). This hybrid, although unexpectedly vigorous, is completely sterile. It is of special interest because of its spontaneous origin. In its natural habitat it might well have escaped the notice of botanists.

Crosses of *Layia glandulosa*, *L. gaillardiooides*, and *L. hieracioides* with *Layia heterotricha*: These three hybrid combinations are of importance because they indicate the remote relation between *L. heterotricha* and other *Layia* species. All four species have 8 pairs of chromosomes. It is very difficult to obtain hybrids between *L. heterotricha* and other species of the genus. The first-generation hybrids between *heterotricha* and two different strains of *glandulosa* were decidedly weaker than the parents; they were able to flower, but were completely sterile. Hybrids between *heterotricha* and *gaillardiooides* developed very slowly, and many died as seedlings. The best hybrid produced only an unbranched stem 7 cm. tall and bore a single head, whereas the parental strains were 50

cm. tall and 40 cm. broad, and bore 30 to 100 heads per plant. The other plants of this combination died as dwarf seedlings. Evidently the parental genomes were so unlike that the metabolism of even the first-generation hybrid was extremely upset. Only one plant of *heterotricha* \times *hieracioides* was obtained. At first it was vigorous, but later it succumbed to a rot in the rosette stage.

Madia gracilis ($n=16$) \times *M. citriodora* ($n=8$): This combination has now been successfully made, and we hope that in time it may produce by amphidiploidy a form similar to the new *Madia* species with 24 pairs of chromosomes discovered in northern California (see Year Book No. 36 [1936-1937], p. 211). The hybrid is very slightly fertile.

PRODUCTION OF AMPHIDIPOLOIDS

Two amphidiploid Madiinae have already been produced. One is *Madia nutans* ($n=9$) \times *M. Rammii* ($n=8$). This new species has become well stabilized in the fourth generation; it has 17 pairs of chromosomes, and is fertile, true to type, and vigorous. It differs in several morphological characters from all other species of *Madia*, and was first mentioned in Year Book No. 35 (1935-1936), p. 212. This artificial new species, produced by the addition of all the chromosomes of two rather rare species, is now ready to be tested for its ability to survive and compete under natural conditions.

The other amphidiploid was produced from *Layia pentachaeta albida* ($n=8$) \times *L. platyglossa* ($n=7$). The parents belong in very different cenospecies, difficult to combine in a cross. In this F₁ hybrid some of the chromosomes pair occasionally, unlike the chromosomes in the *Madia* amphidiploid just mentioned, none of which pair. The new amphidiploid has 15 pairs of chromosomes, is moderately uniform in garden cultures, and differs from both parents and all other species of *Layia*. It appears to be less successful than the amphidiploid from *Madia nutans* \times *Rammii*, but is more vigorous than the diploid F₁. Its branches develop abscission layers next to the main stem and tend to drop off.

Both of these amphidiploids were produced in the garden spontaneously from diploid gametes, not through the application of artificial methods.

FIELD STUDIES

A trip was made by Drs. Keck and Hiesey through the South Coast Ranges of California and along the adjoining coast in May to study the distribution of the 8- and 16-chromosome species previously lumped under *Layia hieracioides* (see Year Book No. 36 [1936-1937], pp. 211-212). Although cytological materials taken on the trip still await study, it seems clear that the diploid species is confined to the area north of Monterey Bay, the tetraploid to the area southward and inland in both the inner and outer Coast Range.

Dr. Clausen obtained a series of *Achillea* transplants along the coast from central California to southern Oregon. This was augmented by a series obtained from coastal Oregon to central Washington by Dr. Keck. A special problem is presented by this genus on the Pacific Coast, for in Oregon the hexaploid species ($n=27$), of the immediate coastal region, is apparently closely pressed by the tetraploid ($n=18$), of the inlands, whereas in central California the tetraploid comes no nearer the coast than at mid-elevations in the Sierra Nevada. The exact boundaries of these morphologically closely similar species and of their ecotypes, and the relation between these two species and the rest of the *A. millefolium* complex, remain to be worked out as one of the problems continued from the transplant experiments.

CYTOTOLOGICAL STUDIES

Material for cytological study has been preserved from practically all the new strains and hybrids grown this year. This amounts to approximately 850 fixations in *Layia* and *Madia* alone. These are to be studied in conjunction with material obtained in previous years, so that a complete cytological investigation will have been made. Dr. Hiesey spent much of the winter and spring upon the

cytology of *Layia* species and hybrids. Dr. Keck also has spent considerable time with the cytology of *Artemisia* and *Penstemon*.

Chromosome counts have been made on a number of species and races in the American members of the *Artemisia vulgaris* complex in connection with a taxonomic study. The following chromosome numbers are additional to the ones reported in Year Book No. 38 (1938-1939), p. 125: *A. Carruthii* (Kansas to Arizona and Chihuahua), $n=9$; *A. serrata* (Minnesota to Illinois and Iowa), $n=18$; and *A. longifolia* (Saskatchewan and Alberta to South Dakota and Wyoming), $n=18$. Added to the previous results, this indicates that the North American species formerly included under the European *Artemisia vulgaris* constitute an interesting polyploid complex well adapted to experimental studies on evolution. A similar situation may obtain in the *Artemisia campestris* complex, where *A. campestris* from the coast of Denmark is found to have 18 pairs of chromosomes, whereas *A. pycnocephala* from the coast of California, recently treated as a subspecies of *campestris*, has only 9 pairs.

SELECTION EXPERIMENT

This experiment has been mentioned in previous reports (see Year Book No. 36 [1936-1937], p. 213, and No. 37 [1937-1938], p. 221). Its purpose has been to exchange and recombine the genes distinguishing the Sierran foothill and alpine ecotypes of *Potentilla glandulosa*, and then to test the relative survival and mode of reaction of the second-generation offspring of this hybrid under three contrasting climates.

As a result of the gene exchange, an extremely variable second generation was produced. The range of its variability and reactions extends beyond that of the parental ecotypes. Each of the approximately 600 plants of this population was divided as a clone and set at all three stations in 1938 in order that its reactions might be studied and compared with those of its parents and of all the previous transplants of this species. No

experiment of this nature has ever before been performed.

In the third year of selection on this F_2 it is found that the results have not been following a predictable pattern. The survival at Timberline is better than would have been anticipated from the known behavior of the foothill grandparent and the F_1 . It is now apparent that at least 50 per cent of the plants set at Timberline will be able to survive a third winter.

New forms that are unlike any plants found in nature have arisen from the cross, and some may be even better adapted to conditions at one station or another than the native races found there. A few appear to have the capacity to survive at all three stations. There are, for instance, plants that in their morphological characters are similar to the foothill ecotype, and, like it, are tall at Mather and Stanford. But they also grow taller than the native alpines in the short summer at Timberline, and seem to be as early and frost-resistant as these. In other words, their morphology and size is that of the foothill ecotype, but they are survivors and possibly even successful competitors in the alpine environment.

This seems to indicate that there has been a recombination of genes determining morphological and physiological characteristics, and that latent possibilities not yet expressed in the evolution of *Potentilla glandulosa* have been released. These findings may prove to be of general importance in plant breeding.

Data from at least four years are needed from the three stations before the observed reactions can be interpreted with confidence. It should, therefore, be possible to conclude the selection experiment after the season of 1942.

STATUS OF PRESENT KNOWLEDGE

Experimentation continues to disclose the great variability in nature. Some variations appear to express only the richness of possibilities connected with the unfolding of life, whereas others serve the more utilitarian purpose of adapting plants to various kinds of

environment. There is no basic difference between the two kinds of variation, but the latter has led to the development of regional ecologic races, the ecotypes.

The separation of living things into species by development of genetic barriers is a secondary phenomenon of great importance for evolution but of no immediate consequence for the adaptation of forms to their environment, or for their survival.

Furthermore, as indicated by the recombinations in the selection experiment, genes evidently determine both morphologic and physiologic characteristics of the ecotypes. Also, certain plant groups have latent evolutionary resources to be released through the crossing of races from very different climates.

How did these climatic races originate? We frankly admit that we do not know. A constantly increasing mass of evidence indicates that environment acts as a sieve that sorts out different hereditary forms into suitable ecological niches by eliminating types not in harmony with it. Also it is observed that different recombinations of climatic races are produced through interbreeding; but how the governing genes originated is still a theoretical problem.

Much general observational evidence proves that climatic races differ markedly in their physiologic properties. Likewise, the recombinations indicate that genes are at the base of the climatic reactions, but it is not known how genes govern the physiologic processes, nor how the latter are related to the striking reactions of plants to different environments.

The data thus far obtained have been of a qualitative sort that outline facts of general biological importance. They should be supplemented, however, with quantitative data from which it would be possible to determine the fundamental physiological characteristics governing organisms in their respective environments. Perhaps no questions in biology hold greater interest than how organisms meet the problems forced upon them by environment, how their reactions are related to their physiological capabilities, and how the latter are related to heredity.

DESERT INVESTIGATIONS

Forrest Shreve, T. D. Mallery, Edith B. Shreve, and W. V. Turnage

DESERT VEGETATION AND FLORA

Investigation of the botanical features of the North American Desert has been largely devoted to work in the northern states of Mexico. This has been necessary because both the floristic and the vegetational features are much less well known for Mexico than for the southwestern United States. With the exception of a few local studies, nothing has been done toward delimiting and describing the types of vegetation represented in northern Mexico. The desert flora of Mexico is incompletely known because it has not been rich enough to attract private or institutional collectors.

The work now in progress embraces the study of both vegetation and flora. The former involves recognition of the various plant communities, the discovery of their extent and boundaries, and the study of their relations to climatic and soil conditions. Thorough knowledge of the flora is an essential basis for vegetational work, for investigation of the floristic history of the desert, and for all work on the plant resources of the region.

Preparation of manuscript embodying the results of work on the vegetation of the Sonoran Desert has been one of the principal activities of the year. Seven subdivisions of the area have been delimited and are given separate treatment. These range from the very arid region at the head of the Gulf of California and in the "rain shadow" of the San Jacinto, Cuyamaca, and San Pedro Martir Mountains, to the foothills of the Sierra Madre, in Sonora, where desert habitats are closely interlocked with open thorn forest or evergreen oak woodland. From the former area to the latter the rainfall increases from about 4 inches to about 14 inches. Also there is an increase in the percentage of the annual total which falls in the summer months. To the treatment of the natural vegetation will be added a section describing a number of the dominant plants. This section will include maps showing distribution, description of

such characteristics of the plants as cannot be learned from herbarium specimens, and as much as it has been possible to find out about the habitat requirements and life histories of the plants. A large collection of living plants from the remoter parts of the Sonoran Desert is still contributing to this phase of the work.

During the year Dr. I. L. Wiggins has made substantial progress in the preparation of the Flora of the Sonoran Desert, which will be published in conjunction with the volume on the vegetation. Manuscript has been completed for the Leguminosae, and the cooperation of Dr. J. R. Swallen, of the Smithsonian Institution, has been secured for the text on the Gramineae. These families, with the Compositae, will form nearly one-third of the entire flora. Manuscript has also been completed by Dr. Wiggins for a large number of the smaller plant families.

Investigation of the Chihuahuan Desert was begun in 1938 as a five-year program organized after the plan of the Sonoran Desert project and with similar aims. Two field seasons have now been given to the work, with fruitful results on both vegetation and flora.

Dr. Shreve and Dr. Mallery spent two months in northern Mexico in the summer of 1939, visiting areas not covered in the work of the previous year. The southwestern and southern edge of the Chihuahuan Desert was explored in the states of Durango, Zacatecas, and San Luis Potosí, making it possible to draw the boundaries of the desert in that region. Only in northern Coahuila are the limits of the desert yet to be determined. In setting the limits of the Chihuahuan Desert it has been found important to give some study to the areas which are adjacent to it but definitely not a part of the desert. The criteria employed are the physiognomy of the vegetation, the structure of the communities, and the floristic composition, and an effort is made to give equal weight to the three.

On its western edge in Chihuahua the desert merges rapidly into grassland in a

transition similar to that which is spread over a broader area in western Texas and New Mexico. In southern Durango and northern Zacatecas there are extensive grasslands lying from 500 to 1000 feet higher than in Texas and northern Chihuahua. The transition from desert to the southern grasslands involves the occurrence of a broad belt of vegetation which has been designated "cactus savanna." With a continuous or broken sod of grasses, this vegetation is dominated by an open stand of *Acacia tortuosa* and two erect platyopuntias, *Opuntia streptacantha* and *O. durangensis*, which reach a height of 15 to 20 feet. The fact that the dominant plants of this vegetation occur neither in the desert nor in the grassland makes it necessary to regard the cactus savanna as a distinct type of vegetation rather than a transition.

Grasses are somewhat more abundant in the Chihuahuan Desert than in the Sonoran, except on the extensive areas of limestone. On the sterile and poorly covered gypsum plains at 5000 to 5500 feet there is often a very open stand of *Bouteloua Rothrockii*. In northeastern and eastern Chihuahua there are numerous undrained basins, over the area commonly designated on maps as the "Bolson de Mapimi." Some of these receive the drainage of large streams rising in the Sierra Madre Occidental, and consist of an alkaline plain with a central dry lake. The vegetation is low and open, with species of *Atriplex* dominating it. The undrained basins which receive only local drainage have a central floor covered with deep alluvial soil and dominated by nearly pure stands of *Hilaria mutica*. Although these *llanos* are often from 10 to 20 miles in diameter, they are not to be regarded as part of the true grassland formation. The outwash slopes surrounding them are covered with characteristic desert vegetation. Such local grasslands, like the very local forests of larger trees, must be regarded as edaphic desert associations. Similar but smaller areas of *Hilaria* are found in the Sonoran Desert at elevations of 500 to 1000 feet.

The eastern and southeastern boundary of the Chihuahuan Desert is sharply drawn in many localities by the Sierra Madre Oriental.

In other places it merges rapidly into the arid bushland which covers the plains of Nuevo León or into a less arid and heavier bushland characteristic of elevations above 5500 feet in Zacatecas and San Luis Potosí. The occurrence of heavy bushland, and the conditions which favor it, is found to set the southern limit of many of the characteristic plants of the Chihuahuan Desert. For example, *Larrea* and *Flourensia* are very uncommon in the heavy stands of shrubs, and in spite of their ability to take advantage of increased supplies of water they are doubtless here limited by unfavorable conditions for germination and early growth.

On the isolated mountains of the Chihuahuan Desert, with basal elevations of 4000 to 5000 feet, there is a very gradual change in vegetation with increasing altitude. Oaks and pinyons occur in favorable locations about 2000 feet above the floor of the desert, but characteristic desert plants range much higher than the lowest occurrences of trees. In northern Zacatecas *Larrea*, *Ephedra*, *Yucca*, *Dyssodia*, and other desert species were found at an elevation of 8600 feet, associated with *Pinus pinceana*, *P. cembroides*, *Lindleyella mespiloides*, and *Juniperus mexicana*.

The preparation of a Flora of the Chihuahuan Desert has been undertaken by Dr. I. M. Johnston, of the Arnold Arboretum of Harvard University. Organization of this work has been begun, and Dr. Johnston has found himself favorably located for consultation of nearly all the early collections of plants made in northern Mexico. The principal needs in the floristic work are collections from the poorly explored central part of the area, and adequate material to give a better knowledge of the geographic ranges of both common and infrequent plants. In the summer of 1938 Dr. Johnston made a collection of 1000 numbers, which proved to be particularly rich in novelties from the arid central basins and the gypsum soils. In the summer of 1939 Dr. Shreve and Dr. Mallory secured about 500 plants, which were placed in Dr. Johnston's hands for study. Through the cooperation of Dr. H. H. Bartlett, of the University of Michigan, Dr. Johnston also received a set of

1600 plants collected in 1939 by Mr. Stephen S. White and Mr. LeRoy H. Harvey in the Chihuahuan Desert and adjacent regions.

RAINFALL

Mr. Turnage and Dr. Mallory have prepared for publication a paper entitled "An Analysis of Rainfall in the Sonoran Desert and Adjacent Territory." This contribution is based on all the general and special rainfall observations made at the Desert Laboratory over a period of more than 20 years, on the U. S. Weather Bureau records for the territory involved, and on the records of the Mexican Meteorological Service for stations in Sonora. The amounts and seasonal distribution of rainfall have been determined, and the dynamics of the summer and winter rainstorms has been analyzed. The larger geographic influences and the local topographic ones have been discussed. Stations on the slopes of low mountains or on abrupt peaks have a rainfall below the normal for the region, while those on the slopes of high mountains, in deep canyons, or to the leeward of higher land have a rainfall above the normal. These influences are more potent in the winter period than in the summer. In the northwestern half of the Sonoran Desert the winter rain exceeds the summer rain, but in the southeastern half the reverse is true. A relatively high percentage of winter rain is found in the parts of Arizona which are dominated by a type of chaparral closely resembling that found in the winter rain belt of the Pacific Coast. In the southeastern part of the Sonoran Desert the most favorable habitats are occupied by thorn forest, a formation which dominates the region immediately south of the desert, in which from 70 to 80 per cent of the rain falls in the summer. In the central part of the Sonoran Desert individual showers are more erratic from place to place in summer than in winter. For the winter season as a whole, however, the rain is more erratic from spot to spot in a small area than is the rain of the entire summer season. Concomitant rainfall variations in space and time show the winter season to have more marked extremes than the sum-

mer. When rainfall is plotted against elevation, the area investigated can be divided into three geographical regions in winter and four in summer, the stations grouping themselves around a curve calculated by the method of least squares. The scatter of the stations away from the several curves can be interpreted as due to the nearness of the station to another region or to the relief of the land in the vicinity. The normal rainfall is greater in relation to altitude in the southern part of the Sonoran Desert than in the northern. The opinion is expressed that little more can be learned from continued observations of rainfall at the present sporadically located series of stations. A new approach to the study of rainfall is now desirable, from the meteorological rather than the climatological standpoint. Important needs are the study of topographic influences, the investigation of rainfall patterns in small areas, and supplementary studies of rainfall intensity, runoff, and soil moisture.

EVAPORATION

Mrs. Edith B. Shreve has continued her investigation of evaporation with a view to securing a reliable norm which can be used in evaluating the rates of transpiration from plants. The work has been directed toward testing the Livingston atmometer, which has been criticized as not giving readings which are proportional to a wide range of the conditions which determine evaporation and greatly influence the water loss of plants. Porous plates 2 mm. thick, of various sizes and shapes, were connected to a source of water and exposed to the air in positions simulating those of plant leaves. Evaporation rates per unit area were measured under many kinds of natural conditions and under various controlled conditions of temperature, humidity, and wind velocity. The shape and angle of exposure of the plates were found to be of relatively small importance as compared with the area. The evaporation per unit area was found to vary inversely with the 0.3 power of the area under all conditions. These conditions included wind velocities from 0 to 20 miles per hour, temperatures

from 108° to 45° F., and wet-bulb depressions from 30° to 10° . The role of the area of the porous plates in their evaporation per unit area indicates that comparison of the rates of transpiration from plants of different leaf size may lead to erroneous conclusions. Water losses from the same plates were measured simultaneously with those from the atmometer. The relation was linear for any one size for all conditions and can be expressed as a simple ratio E/E' , in which E is the evaporation from the plates and E' that from the atmometer. However, the ratios change with area according to the equation

$E/E' = 2.5/A^3$. If transpiration per unit area from a plant is substituted for evaporation from the plates, and the size of an average leaf is used for the area, an expression is obtained which can be used to evaluate transpiration in terms of the evaporative conditions of the environment. If the expression $T/E \times 2.5/A^3$ is used, where T is the transpiration per unit area, E the evaporation per unit area from the atmometer, and A the area of a leaf of average size from the plant used, then the Livingston atmometer may be used as a norm in the investigation of the water relations of plants.

ECOLOGY

ADAPTATION AND ORIGIN

F. E. Clements, F. L. Long, and E. V. Martin

Evaporation and transpiration under controlled conditions. In the attempt to evaluate the functional responses of adapted plants, experiments have been carried on in a dark-room as completely sealed as possible by means of a metal lining. These have dealt with evaporation from wet blotting paper and transpiration from *Helianthus annuus* and *Ambrosia trifida*, with the atmospheric factors under control. The latter ranged from 15 to 85 per cent relative humidity and 80° to 120° F., with wind velocities around 500 ft./min. Evaporation from wet blotting paper (essentially a free-water surface) follows the known laws, being proportional to the difference between the saturation vapor pressure at the temperature of the evaporating surface and the vapor pressure in the surrounding atmosphere. Wind increases the rate of evaporation, with a consequent increase in the factor of proportionality between evaporation rate and vapor-pressure difference.

The transpiration of *Helianthus annuus* (both Russian Mammoth and selfed Canadian strains) and *Ambrosia trifida* seems to be practically identical under given conditions of air temperature and relative humidity, in the absence of wind and radiation. The relation between transpiration rate and relative humidity at a given temperature appears to

be linear throughout the humidity range. At a given relative humidity the transpiration rate at 120° F. was four times that at 80° F. These ratios are quite different from those obtained for evaporation from wet blotting paper; the evaporation rate at 120° was about 1.35 times that at 100° and 1.90 times that at 80° . An interesting point was the discovery that at 120° F. transpiration and evaporation were very nearly equal; in other words, at this temperature leaves behaved almost like free-water surfaces. However, at 80° F. the rate of transpiration was only about half that of evaporation. The explanation may lie in an increase of the permeability of the cuticle with the higher temperatures, or in a change of protoplasmic properties.

Evidence in support of this hypothesis was obtained from experiments dealing with the effect of wind on the transpiration rate. A velocity of 500 ft./min. increased the transpiration rate 15 to 25 per cent at a temperature of 80° F., about 50 per cent at 100° , and between 200 and 300 per cent at 120° . These values are in contrast with an increase of 500 per cent in rate of evaporation from the blotting paper at this velocity. The calculations of Brown and Escombe show that wind should increase the stomatal component of transpiration in *Helianthus annuus* only about 25 per cent, which appears to be nearly the value obtained in these experiments at an air temperature of 80° F. As the temper-

ature increases, however, the leaves more nearly approach the blotting paper in behavior, indicating an increase in the cuticular component of transpiration.

Transpiration at all three temperatures employed exhibited a very close correlation with the vapor-pressure deficit of the atmosphere, and did not follow the laws controlling evaporation from a free-water surface as represented by the wet blotting paper.

The temperatures of blotting paper and leaves were measured by means of thermocouples. It was found that Newton's law of cooling held over a range of about 20° C.; beyond this limit the relation departed slightly from linearity. The maximum cooling of leaves at an air temperature of 120° F. was 13° C., although at an air temperature of about 140° F. a drop of 20° C. below the air temperature was observed. The rates of transpiration ordinarily found in nature will seldom produce depressions in leaf temperature of more than 10° C. below air temperature.

Transpiration rates of native transplants. The following comparisons are drawn from native transplants grown in phytometer containers at the Alpine Laboratory. In 32 independent comparisons of the rate of transpiration in sun and shade forms of a given species (21 species being tested), it was found that when both forms were in the shade, in 25 cases the difference between them was not statistically significant. However, with both forms in sunlight this was true of but 17 cases. In 14 instances, the sun form maintained a higher rate of loss than the shade plant, and in 1, the reverse was true.

In testing the response of climatic forms, it was found that for 6 species, the plants at the plains and montane gardens had the same rates in a given environment, while for *Helianthus annuus* the plains form gave a slightly lower rate than the montane. Nine comparisons were made between montane and alpine forms; in 2 the forms were equivalent, in 3 the montane plants yielded the higher rates, and in 4 the alpine forms were higher. Plants grown in lath-houses at the three climatic stations indicate that the plains and montane shade plants have about the same transpira-

tion rate in the same conditions, while the alpine shade plants have a somewhat higher rate of loss.

When the various forms are tested in the habitats in which they are grown, the usual order in terms of transpiration rate is the following: plains highest, montane next, and alpine lowest, with the lath-houses at each station giving rates about half those in the sun at the same station.

Transpiration of cut shoots from adapted forms. The water loss of cut shoots for 3-minute intervals was determined by weighing them on an analytical balance, using a number of species for each adaptation series at Santa Barbara. The data were restricted to a comparison of the rates per unit of leaf area of plants of a given species growing in the various habitats. Six species were utilized from the ridge and shelter gardens of the coastal sand dunes, both forms being tested side by side in the shelter habitat. No difference could be detected in the response of *Oenothera trichocalyx* and *Rudbeckia bicolor*, but in the other 4, *Antirrhinum hispanicum*, *Chrysanthemum coronarium*, *Agrostemma githago*, and *Gaillardia hybrida*, the rates for the ridge forms were but 65 to 85 per cent as high as for the shelter-garden plants. In all species, the ridge plants are so much smaller than the latter that the total transpiration per plant would be several times as great in the shelter garden.

For comparing the rate of transpiration in sun and shade shoots, 7 species were employed from this series (approximately 100, 50, and 12 per cent light intensity), and 6 from the in-and-out huts with branches of the same plant in sun and in shade. Of 18 sets, each with an average of four trials, 2 gave a lower rate for the shade than for the sun, 3 gave equal rates, and in 13 the rate for the shade form was from 20 to 400 per cent greater. For the in-and-out species, the rates for the "in" shoots were in all instances lower than for the "out" ones, the ratios being from 37 to 79 per cent.

In the fertilizer-water series, namely, NW-0, NW-1, and NW-2, five species exhibited decreasing transpiration rates in this

order. The plants in NW-0 gave an average rate about twice that in NW-2, while those in NW-1 were fairly intermediate. In the soil pits, the plants grown in sand and clay yielded higher rates for three species than those in garden loam. Comparable results were obtained for the length-of-day series, as well as for *Mimulus cardinalis* in four adapted sets, viz., nutrient-water, soil pit, sun and shade, and length of day.

Phytometer measurements in factor series. A phytometer battery of 10 plants of *Helianthus annuus* was installed in each of the following habitats: dune ridge, shelter garden, sun main garden, 9- and 5-hour length-of-day sheds, and lath-houses with 75, 50, 25, and 12 per cent light intensity. The results were as shown in the accompanying table.

Habitat	Total dry wt. (g.)	Total transpiration (g.)	Water requirement (g./g.)
Ridge garden.....	1.05	394	385
Shelter garden.....	5.93	1490	254
Main garden.....	49.10	7241	147
Lath-house 75 %...	34.60	5614	162
Lath-house 50 %...	17.70	3254	184
Lath-house 25 %...	9.20	1781	194
Lath-house 12 %...	3.10	800	258
9-hour shed.....	21.71	3981	183
5-hour shed.....	9.20	2382	259

Transpiration rates in g./dm.²/day were calculated for weekly intervals during a period of 7 weeks. The average rate was 13.6 for the ridge and 13.7 for the shelter garden.

Dry-weight increment of four series. Batteries of 64 free phytometers (*Helianthus annuus*) were transplanted to each of twelve different habitats in the adaptation gardens for measuring the rate of growth as recorded by dry weight. Eight plants of these were harvested each week for a period of 8 weeks. With few exceptions, the weekly increments in the various habitats bear a relation to each other corresponding to the final dry weights shown in the accompanying table. The relative increment ("net assimilation rate" of Gregory) was derived by dividing the dry weight by the average leaf area, and is ex-

pressed in units of grams per square decimeter per week over a 9-week period.

Habitat	Final dry wt. (g.)	Relative increment
Ridge garden.....	0.35	0.158
Shelter garden.....	1.48	0.292
NW-0 (main garden)...	31.90	0.539
NW-1.....	56.20	0.631
NW-2.....	72.40	0.706
Loam.....	50.60	0.556
Adobe.....	12.70	0.356
Sand.....	0.81	0.156
Lath-house 75 %.....	25.90	0.362
Lath-house 50 %.....	15.85	0.267
Lath-house 25 %.....	4.12	0.173
Lath-house 12 %.....	0.82	0.070

This experiment was duplicated for five habitats, employing batteries of 150 plants and determining the leaf area and dry weight of 25 each week for 6 weeks, the resulting values being comparable with those above. Similar determinations were made for the three climatic and ten edaphic stations at the Alpine Laboratory in 1939, and the results are undergoing further check during the current season.

In the continued endeavor to develop a short, compact form of sunflower, especially adapted to the requirements for phytometers, a new strain, PU, has been obtained from Canadian S-490, supplied by the Department of Agronomy of the University of Saskatchewan. The individuals were far more uniform than in the other strains grown, the coefficient of variability for stem height being 1.55 per cent, as compared with 20.51 per cent for the red sunflower. For leaf area the coefficient was 4.59 per cent, the next lowest, 7.75 per cent, being found in the Russian Mammoth.

CLIMATE, CLIMAX, AND CONSERVATION

F. E. Clements and E. S. Clements

The drought decade and sunspot numbers. The prediction that the recent sunspot maximum would reflect the double cycle and reach a yearly mean of more than 100 has been verified by a plateau of three years with an average of 104 spots. This followed the work-

ing rule in being accompanied by a period of generally intense drought. It was further assumed that the number would drop rapidly in the fall of 1939, the drop to mark the beginning of good rains in California and a precipitation above normal for the West as a whole. This assumption proved correct for southern California and is in process of being justified elsewhere.

The seasonal distribution of rainfall during the three years of the plateau appears also to bear a close relation to the monthly sunspot means. For the most part, late spring and summer were very dry, coinciding with a 5-month average of 128 spots in 1937, 122 in 1938, and 108 in 1939. Months with low spottedness in the early spring were generally about normal, and similar months in autumn were likewise more or less rainy. Such a correspondence has been noted a number of times in previous years, but the existence of a rule is still to be determined. Theoretically, it is logical to expect that abrupt changes in number during the year will produce effects resembling those of like changes from year to year.

It is well understood that a major difficulty in verifying forecasts arises from the seemingly fortuitous variations in rainfall from region to region, a situation complicated by the present necessity of keeping records by states and sections. In order to evaluate this factor more closely, an analysis has been made for the critical tier of prairie states, viz., North Dakota to Texas, for the past decade. In the five years of serious drought, 1931, 1933, 1934, 1937, and 1939, all the states agreed in exhibiting a minus departure, and the accord for 1930 was nearly complete. For the one good year, 1935, South Dakota alone gave a minus departure, while for the relatively good year 1938, South Dakota and Texas recorded 88 per cent of the normal at one extreme and Kansas 102 at the other. For 1932, there were four plus and two minus values, but none of these was excessive in amount. Nebraska and Kansas gave the same sign for every year of the decade; North and South Dakota were in harmony each year but

one, and Oklahoma and Texas were in moderate disagreement for two years.

The variation to be reckoned with in forecasting the rainfall of a particular state may be illustrated by the case of Nebraska. Since 1871 there have been but 4 years in which all stations showed minus signs and but 2 in which all departures were plus. On the other hand, the departures for 28 of the past 46 years, in which the number of stations exceeded 50, have amounted to 2 inches or more and have concerned three-fourths of all stations. In 9 other cases, the difference has been less than 1 inch and hence of little significance, while for the remaining 9 years the average departure has been between 1 and 2 inches and not critical.

A method of compensation for drought. Though drought periods are now known to be recurrent and inevitable, it is not yet realized that the methods of compensation and conservation available are adequate to eliminate their major effects. The various processes concerned have been developed independently, and the present need is to organize them into a complete system for evading drought. The first task is to bring about their proper coordination, and this can be done only by practical tests, such as have been proposed.

An adequate system of compensation must take into consideration the advance made in long-range forecasting during the past decade. In this period the predictions of monsoon rains in India have achieved a rating of 82 per cent, and this record has been approached by several investigators in the United States. The present need is to test the various indices in a much larger number of areas and regions and to determine their value for anticipating seasonal distribution as well as the annual departure. In addition to rainfall, it is possible to forecast temperatures and consequent evaporation, both of which are concerned in the fate of the water that enters the soil. The amount of moisture in the soil at any time is easily determined and, with the record of its changes from time to time, affords an invaluable prediction of probable crop yields. The most striking application of this method

has been to fields of winter wheat with summer fallow, where it all but insures the equivalent of an average annual crop, but it can be applied with similar success to other cultivated and native crops.

In dry years or arid regions, only about a third of the rain that falls becomes available to plant roots. The major portion is lost through interception, runoff, and evaporation from the soil surface. Loss by interception is governed by the type of rain and the kind of cover, and is practically unavoidable. On the other hand, runoff may be reduced to the vanishing point, and evaporation may be cut down to a fourth or less of the normal. Such savings constitute the direct compensation for drought and aridity; appropriate measures have been extensively developed and only await decisive test through incorporation in the compensating system. The problem of filtering water into the soil, with corresponding control of runoff, erosion, and flooding, has been largely solved and the process requires only certain refinements. At present these involve chiefly the interaction of cover and intimate structures, such as small furrows or trenches, though ultimately the major reliance will be placed upon plant life. In the steps to be taken for reducing evaporation losses from the soil, stubble, straw, hay, and dry weeds constitute the outstanding materials. Dead rooted cover surpasses all other types of mulch in total effectiveness when penetration, control of wind and water, evaporation, and transpiration losses are taken into account.

In the study of succession in abandoned fields, recovery was found to be far more rapid after the sketchy tillage of the "suitcase farmer" than elsewhere. Shallow plowing at the outset and the practice of drilling seed for the next wheat crop into the headed stubble without further cultivation explained the good tilth and the persistence of grass crowns and rhizomes. What was generally regarded as a shiftless practice was actually a new way of securing the values just mentioned, and in addition a fair control of weeds with their high transpiration waste. It was further assumed that this control could be rendered

nearly as complete as that with bare summer fallow by using a subtiler blade to sever the roots and at the same time loosen the soil without turning it up. An additional advantage is that of maintaining the soil profile in its optimum nutrient relations, a factor too often overlooked in the traditional "good" tillage. For this purpose several implements are now available, but the most satisfactory are those that leave the headed stubble upright. With sufficient draft, it will become feasible to carry out harvesting and subtiling in one operation.

Two other features of critical import are, first, a prompt and accurate land-use survey, by which crop lands may be set aside from range or fields to be regrassed, on the basis of the methods outlined above; second, crop adjustment to the soil-water capital and the probable rainfall, together with crop specialization, which is already well advanced through the efforts of the various experiment stations. Finally, application of the principles and methods of bio-ecology is essential to the treatment of each farm as an organized unit, and has definite though indirect effect in minimizing the impact of drought, both economically and socially. Control of rodents and predators of all kinds, game management for waterfowl, quail, grouse, and pheasants, ponds for fish, muskrats, and beaver, and proper stocking with the various domestic animals will afford full scope for establishing a working balance between plants and animals on the farmstead.

Installation of experimental grids. Public discussion of the necessity of purchasing marginal farms and returning them to grassland has led to the general assumption that this is a simple matter and one easy of accomplishment. The facts, however, are quite otherwise, for the desultory attempts to reseed depleted areas of climax grassland during the past thirty years have regularly eventuated in failure. Success has been more frequent in the recent projects of the Soil Conservation Service, but it is still the exception rather than the rule. When proper account is taken of the vast extent of original climax prairie, its wide range of climate, and the large number

of associations and faciations and the many types of disturbance and stages of succession in it, it is evident that no simple set of processes and groups of materials will prove adequate to the task. To blaze trails through such a maze of conditions and species is a formidable undertaking, and one which will be as continuous as progress in all other agricultural fields. But it is different in having almost no background of experience or knowledge, and the pressure of events is such that it cannot await the slow piecemeal acquisition of the necessary facts. To meet this need promptly and adequately, the method of experimental grids has been developed to organize large numbers of field and evaluation plots into a comprehensive system, with checks and comparisons as major tools.

As a quantitative method of studying factors, processes, and living materials in the field, the grid ranks with the quadrat and has an equally wide range of uses. Perhaps its greatest value lies in closing the gap between nursery beds or test plots and large-scale operations on projects, and in providing answers much more rapidly, cheaply, and certainly than these can. Its chief purpose at present is to solve quickly the many detailed questions that have arisen in connection with regrassing, especially by seeding, but it has a place wherever experimental results are needed to guide field operations. It may be applied to cultivated fields, highway landscaping, wood lots, windbreaks, forest planting, game refuges, etc., whenever it is desirable to replace personal observations and judgments with quantitative results and standards.

The standard type of grid is designed to compare the performance of as many species, methods, and processes as a project may demand. By contrast, a special grid may confine itself to one factor or process, such as adaptation, acclimatization, competition, rate and date of seeding, mulches, structures, etc. The two types may be combined to form a master grid, in which the standard form is supplemented by one or two special grids near at hand or in the same general locality. A typical grid drawn up for the mixed prairie

of the Great Plains comprises ten of the most important grass dominants, two introduced grasses, and a mixture of mid-grasses, of short-grasses, and of mid- and short-grasses. These are crossed by untilled and subtilled nurse plots, similar mulch plots, a pair with small trenches $1\frac{1}{2}$ and 3 feet apart, and still others with fertilizer and with native and cultivated legumes. A competition grid consists of a number of selected species of grasses, with or without forbs or shrubs, crisscrossed to match each species with all the others. The adaptation grid is devised to reveal the qualities of climatic and edaphic strains of grasses especially, and to show the rate and degree to which these may be modified in a series of regions.

Though the immediate objective of grid installations is to meet the practical needs of conservation projects, it is evident that they will make an increasingly important contribution to the experimental and quantitative foundation of dynamic ecology. It is fortunate that the principles and methods of the latter are undergoing test on such an extensive scale. This novel cooperation will be to the great advantage of both ecological research and practice.

The ecological basis for regrassing. Throughout the grassland climate and climax, the grass cover will be restored by the natural process of succession when the disturbance ceases wholly or in large part. The rate at which this restoration takes place depends primarily upon the supply of seeds or other parts; it is rapid wherever rootstocks have persisted in the soil, and exceedingly slow when seeds must come in from neighboring pastures and roadsides, as is the usual case. The rigor of conditions as to germination and seedling establishment often plays a decisive part likewise, notably in the hot, dry desert plains of the Southwest. On the lower levels of this association, the grass relicts are so small and few, the soil is so depleted by erosion, and temperature and evaporation are so excessive that succession is all but impossible, and the disclimax desert scrub will remain in possession for a long time to come. In consequence, natural succession can be

depended upon for recovery only under exceptional circumstances, and for rapid restoration must be supplanted by artificial methods that speed it up greatly.

However, the requirements for success with artificial succession are essentially identical with those for the natural process. The ruling disturbance must be stopped, as well as such accessory ones as grazing and rodent action; seed must be supplied in large amount and properly planted, infiltration increased, erosion and evaporation diminished, and competition reduced to a minimum. The probability of securing an adequate stand will be enhanced if seeding is done in the light of the record of soil moisture and with some consideration of the rainfall cycle in general and the special pattern of the region concerned. The ecological rule is to reproduce the natural process in essentials but to telescope the stages into two or three at the most by controlling conditions and greatly increasing the seed supply. In the case of such vigorous colonizers as sand dropseed or crested wheat grass, a dense, pure stand may be obtained the first year in the proper climate for each, but this will probably not be the final stage, as indicated later.

A significant corollary to the principle of adaptation is to the effect that native species, particularly climax grasses, are better suited to their particular subclimate than are alien ones. This not only is logical from the theoretical standpoint, but also derives strong support from the results of a quarter-century in transplant gardens. It is also confirmed by the behavior of grass populations of one species drawn from different portions of its range. Thus, seeds of blue grama from the northern Great Plains have been found to germinate and to bloom and set seed earlier than those from the southern, and the plants are but a third or a fourth the size. Plants from intermediate stations only a few hundred miles apart form distinct intergrades in all these respects. These constitute new acquired characteristics of less fixity within the more permanent climatic pattern fixed much earlier in terms of boreal or northern ("winter") grasses and subtropical or southern

("summer") ones. The extent to which such climatic and edaphic strains can be modified by different environments is now being investigated on a much larger scale by means of regional grids.

Crested wheat grass, a native of Eurasia, has made such a remarkable record in Canada and the northern prairie states as to appear exempt from the rule mentioned above. With wider tests and more detailed records, however, it is becoming evident that the exception is more apparent than real. Not only do some of the best natives give promise of excelling it in establishment and yield, but definite proof is being obtained to show that they exceed it in competitive equipment, and a number of installations are now being studied to test this point. However, although it is important to know the precise role of crested wheat grass in regrassing, it is less necessary as a practical matter. If this species maintains itself permanently on the range without some form of semicultivation, it will have justified its use, and if it gives way before the competition of the natives, a better-adapted cover will be in possession. From the preliminary evidence, crested wheat grass should turn out to be a "subclimax" grass in the artificial succession for regrassing.

A different type of restoration, but one equally entitled to the term regrassing, has been well justified by the initial experiments and is now on the eve of being widely extended by means of the grid method. This is the re-establishment of climax grassland by burning off the sagebrush, which today forms the characteristic disclimax of the Great Basin and extends well beyond its borders. No other method can compare with this in the quickness and cheapness with which a vast acreage can be returned to productive grassland. This is said with full realization that fire is a dangerous tool and should never be employed except under competent and experienced direction. Regions differ much, however, in physical conditions, in the age and stand of sagebrush, in the quantity and species of the grass relicts, and in the grazing system. Most critical of all perhaps is the time of burning, with respect to the rate at which

the fire runs and the risk of injury to the grass. The immediate task is to perfect the method of burning for each distinct area by means of adequate grid installations and then to proceed with the practical program as rapidly as grazing demands warrant.

The origin and nature of oak barrens and openings. From time to time these peculiar communities of the oak-hickory association of the deciduous climax have been studied in the course of field trips through the East, and an opportunity was found to compare them more in detail in the autumn of 1939. The floristics of the oak openings in Ohio have been extensively treated by Moseley, and the Kentucky barrens have been comprehensively discussed by Dicken. In spite of the difference in name and the marked divergence of the soils, these are much alike in origin, in climatic and seral relations, in composition, and in problems of utilization. In essence, they are inclusions of the tall-grass post-climax swept into the deciduous forest from the southwest during the major warm-dry phase of the post-Pleistocene. With the return of the cool-moist forest climate, the grasses found refuge in the shallow limestone soils of the barrens or the sands of the openings, where conditions favored them in competition with trees. How narrow this advantage is may be readily seen from the invasion of small trees and shrubs in both communities, and there must always have been a successional trend toward the climax, fluctuating with the climatic cycle and often upset or much modified by man. A similar phenomenon is to be observed in the Indiana dunes about Lake Michigan today, but the succession is still active and hence the stages are much more distinct. The same general relation of forest to prairie now prevails throughout the ecotone between them. What seems to be the same but is actually a reversed relation characterizes the Cross Timbers of Texas and the similar woodlands of Oklahoma, in which sand has provided trees with the needed compensation against a prairie climate.

The origin of the prairie was a topic much debated before the rise of dynamic ecology,

and various explanations continue to be offered by those little or not at all versed in vegetation. The evidence from paleo-ecology, however, permits no doubt that the prairie, like other great climaxses, is a product of climate and as such has been in existence for some millions of years. Throughout this time, it has been subject to climatic shifts and has moved forward or backward under the compulsion of warm-dry or cool-moist phases of major climatic cycles. Chief among these have been glacial-interglacial cycles, and the present distribution of the prairie bears the impress of the latest of these. As a consequence, prairie inclusions are still to be found far beyond their proper climate and have been a perennial puzzle to those unfamiliar with the history of vegetation.

As such a great relict area, the barrens of Kentucky and neighboring states have been the object of all possible interpretations, among which fire has easily ranked first. Fire, however, could not have originated the grassy tracts, nor could it have extended them, since years of annual fires can do no more than reduce hardwoods to the condition of scrub. Clearing could have had only a secondary minor effect, and the herds of buffalo practically none at all. By far the most probable course of events was a climatic change toward dryness, marked by the forward movement of prairie, followed by a return of the moist forest climate (a rainfall of 45 to 50 inches), the persistence of grassland areas on shallow limestone soil, readily dried by widespread underdrainage, the formation of swamps, especially canebrakes, followed by succession to savanna, and finally a wide range of disturbance effects, of which cultivation and fire were the chief.

The biotic significance of disturbance. Field observations to the effect that rodents in general prefer disturbed areas in grassland have been confirmed by the results from rodent-proof exclosures, in northern Arizona especially. These regularly contain a larger percentage of forbs than does the range outside or the cattle-proof unit which is open to rodents. After the forbs had disappeared

from the latter, a small plot was fenced with hardware cloth, and the forbs reappeared in a few years, only to vanish again when the fence was removed. The preferences of prairie dogs have also been determined by noting the various species utilized for food. In one large town in the mixed prairie, 15 species had been eaten to some degree, whereas none of the grasses had so far been touched. This by no means signifies that rodents do not consume grass, but the latter seems to be a second choice, except when forbs are few or hard, or a protected range adjoins a depleted area. A novel instance of this fact has occurred in recent years of drought, during which pocket gophers have moved out of pastures and meadows in large numbers, to occupy the better-watered, greener shoulders and shallow ditches of roadsides. In some cases the mounds are almost continuous, with a high density for a score or more of miles,

constituting an infestation such as has never been observed in natural cover.

The initial disturbance that leads to the invasion or increase of rodents usually results in renewed disturbance on a larger scale, which brings about a disclimax more or less typical of the species concerned. Though the change in composition may be pronounced, such areas are relatively quite insignificant and temporary, and commonly return to the climax condition within a few years after abandonment. No matter how great the control may seem at the maximum, all the grazing animals, from prairie dog and jack-rabbit to antelope and bison, wild horses and cattle, exert only a transient effect upon the climax. Their major influence is due to coaction and hence they are known as influents, by contrast with the plant dominants, which owe their mastery of the climax to reaction upon the habitat.

PALEOBOTANY

Ralph W. Chaney

During the past year the study of the Shanwang flora has been completed in cooperation with Dr. Hsen Hsu Hu, and a paper submitted for publication. This flora from Shantung Province, China, is well represented in numbers both of specimens and of species. Unlike many Tertiary collections, it includes numerous fruits as well as leaf impressions. Fossil plants of the same age are so widely distributed in western North America and Europe that a reasonably complete picture may now be drawn of the character and distribution of forests in the northern hemisphere during the closing stages of the Miocene epoch.

In the Shanwang flora there is definite evidence of a mixture of typically temperate trees with genera now found in regions of warmer climate. Similar mingling of low- and high-latitude genera has been noted in the Upper Miocene floras of western North America and Europe. It is still to be found in the Yangtse Valley, where temperate trees of the upper slopes range downward to the levels occupied by subtropical forms. Such a

modern ecotone is interpreted as resulting from a dynamic environment. The similar overlapping of climatic types in Shantung Province and elsewhere during the Miocene seems also to have resulted from climatic or topographic instability. These Miocene ecotones therefore throw light on the physical history of later Tertiary time, and verify our conclusions, drawn from other data, that this was an epoch of mountain-making and climatic fluctuations. The latter were all in the same direction on the northern continents, an increasing number of subtropical genera indicating rising temperature. This corroborates our opinion that Tertiary climatic changes were widespread rather than local, and that the positions of the continents with relation to the North Pole were essentially as they are today.

Continuation of studies of the Tertiary vegetation of Oregon has centered on Pliocene floras from The Dalles and Troutdale. Additional material has been collected, in cooperation with the Geological Society of America, which indicates a transition from the mild

climates of earlier Tertiary time to the more rigorous climate of today. The disappearance of the redwood and its associates from the area east of the Cascades, and the increasing abundance of oak and box elder, are interpreted as resulting both from world-wide climatic changes and from the local effects of the Cascade uplift. This work in Oregon is closely related to the studies of Dr. Axelrod on the Pliocene of California and Nevada.

The geologic section in the John Day Basin of eastern Oregon has long been recognized as the most complete sequence of terrestrial beds in western North America. The fossil floras contained in these beds are abundant and well preserved. Discovery of closely related floras in bordering areas of Oregon, and in adjacent states in western America, makes possible the assignment of the rocks containing them to their proper levels in the Tertiary section. During the field season of 1939, plant fossils have been collected in Harney County, south of the John Day Basin, in an area where little geologic or paleontologic work has been carried on. These fossils resemble the trees of the Mascall flora of the John Day Basin, a flora closely related in age to the Shanwang flora of China. Geologic studies indicate that volcanic sediments and lavas in this part of southern Oregon may closely correspond to the rock sequence of the John Day Basin, and suggest that other fossils may be found from several horizons which will establish a complete floral sequence.

Investigations of colleagues and students which bear upon problems of Tertiary floral history may be summarized as follows:

D. I. AXELROD. The Mulholland flora, from the Pliocene of west central California, has been studied and a report has been completed for publication. This flora is characterized by evergreen oaks, poplars, and other trees which are believed to have migrated northward from a center of origin in Mexico. Such typical California genera as *Lyonothamnus* and *Fremontia* are listed as fossils for the first time from this and related floras. Other

Pliocene floras in California and Nevada have been collected and are being studied by Dr. Axelrod, who is entering his second year as National Research Council Fellow, with headquarters at the U. S. National Museum in Washington.

C. CONDRIT. Additional collections from the western slopes of the Sierras give a relatively complete picture of the forests and environments in this region toward the close of Tertiary time. Reports on the Remington Hill and Table Mountain floras have been prepared for publication. The Remington Hill flora, which is referred to the late Miocene, is made up largely of genera which have come down from the north, and which are widely represented in Tertiary floras elsewhere in the northern hemisphere. The Table Mountain flora, of early Pliocene age, contains an additional southern element, and approaches in composition the vegetation now living in the Sierra Nevada of California.

H. D. MACGINITIE. The study of the Chalk Bluffs has been completed, and a report on this subtropical forest of the California Eocene has been written. It shows a close resemblance to the vegetation of Mexico at middle elevations, and indicates an environment wholly unlike that now found in the mountains of central California. Dr. MacGinitie is continuing his study of the Florissant flora of the Rocky Mountains area.

B. B. WILDER. Large collections have been made of a Miocene flora in northwestern Oregon. This work has progressed to a point where relations with other Oregon floras have been noted.

The study of Triassic material from Arizona has been brought to completion by L. H. Daugherty. Numerous cycads, ferns, and conifers make this the largest and most significant flora of the Triassic age which has been studied in America for many years. The structure of several well-preserved specimens has received particular emphasis. A climate less arid than that of the Southwest today is indicated by this Chinle flora.

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DEPARTMENT OF EMBRYOLOGY

Baltimore, Maryland

GEORGE W. CORNER, *Director*

The year 1939-1940 has been one of momentous changes in the staff of the Department of Embryology. Dr. George L. Streeter retired from the directorship on May 1, 1940, after twenty-six years' service, twenty-three of them as Director. Dr. Streeter was appointed a staff member on July 1, 1914, and was placed in charge of the Department in 1917 after the untimely death of Dr. Franklin P. Mall, founder and first Director of the laboratory. Having shared intimately in the development of Dr. Mall's plans, Dr. Streeter was eminently successful in carrying on and expanding them. The Department as it now stands, with its unexcelled collection of human embryos, its broad outlook, and its widespread cooperative influence among the embryologists of the world, is a reflection of Dr. Streeter's talents and personality.

The many contributions to the science of embryology which he has made through his personal researches are well known to colleagues everywhere, and have been fully (if perhaps over modestly) reported by him in these Year Books.

It is a matter of great satisfaction to all connected with the Department that Dr. Streeter is to continue his work under a grant from the Carnegie Corporation of New York, and that he is to be in the immediate neighborhood of the laboratory so that his counsel and encouragement will be available.

Dr. Warren H. Lewis, Research Associate, who retired July 1, 1940, was appointed to the staff on August 1, 1919. Dr. Lewis was one of the pioneers in experimental embryology; his work on the factors controlling the development of the lens has indeed become a classic in that field. His major contributions as a member of the Carnegie Institution have been to the science of cytology and its application in the study of histology and of tumor growth, through the method of tissue culture. In this work he is recognized internationally as a leader. Dr. Lewis will continue his work

as a member of the staff of the Wistar Institute of Anatomy and Biology in Philadelphia. It has been arranged that Dr. Margaret R. Lewis will also work at the Wistar Institute, though remaining a Research Associate in the Department of Embryology.

Dr. C. W. Metz was appointed, beginning July 1, 1940, Professor of Zoology in the University of Pennsylvania. Dr. Metz has been associated with the Carnegie Institution during his entire career, having been resident investigator in the Department of Genetics from 1914 to 1930, and Research Associate in the Department of Embryology from 1930 to 1940. In his special field of cytology as applied to genetics he has attained great distinction, as is evidenced by his call to take charge of zoology at Pennsylvania.

Mr. James F. Didusch, who was appointed artist on September 1, 1913, as one of the very first to join the Department, was appointed to succeed, on September 1, 1940, his distinguished teacher, Max Broedel, as head of the Department of Art as Applied to Medicine, in the Johns Hopkins Medical School. Mr. Didusch has brought to his tasks here not only superb draftsmanship, but scientific accuracy and intelligence of a high order. It is not too much to say that by his personal standard of work and his special combination of critical frankness with good will he has helped set and maintain the standards of the laboratory. His hundreds of beautiful and accurate drawings, appearing through the years in the "Contributions to Embryology," have added greatly to the value of the series. We are fortunate that his promotion takes him no farther away than the room next to his former studio, and thus we shall have the opportunity to consult with him.

Dr. Robert K. Burns, Jr., Associate Professor of Anatomy in the University of Rochester, School of Medicine and Dentistry, was appointed a staff member as of July 1,

1940. He is expected to conduct investigations in experimental embryology in mammals.

Dr. Louis B. Flexner, Associate in Anatomy in the Johns Hopkins University, School of Medicine, was appointed Research Associate

as of September 1, 1940, and expects to carry on studies in the physical and chemical aspects of embryology, making use of radioactive substances in cooperation with the Department of Terrestrial Magnetism.

EMBRYOLOGY

ANOTHER EARLY PRIMATE EMBRYO (CHIMPANZEE)

The project of comparative study of early embryos of the various primate species, discussed by Dr. Streeter in previous reports, was continued by the acquisition and study of a 10½-day embryo of the chimpanzee. This specimen was obtained through the cooperation of the Yale Laboratories of Primate Biology, Orange Park, Florida. Previous studies by Yerkes and Elder of that laboratory have made known the time of ovulation of the chimpanzee (i.e., about the 21st day of the 35-day menstrual cycle). Acting upon this information, Dr. Hartman was enabled to operate twice each upon two females at the Yale Laboratories. One of these animals furnished in 1938 the normal embryo "Yerkes A" which is the subject of the present report, and in 1939 an atypical blastocyst "Yerkes B."

Dr. Heuser's study of "Yerkes A" reveals in the first place a picture of implantation almost identical with that in man at a comparable age, as known from such specimens as the Miller ovum and the new embryos of Hertig and Rock (Carnegie 7699, 7700) mentioned in Year Book No. 38 and now in process of full study and description. The ovum is buried in the uterine mucosa immediately beneath the endometrium and surrounded by an early trophoblast. The embryo proper is similar to the earliest human embryos and to those of the rhesus monkey of similar ages, but differs somewhat in the precocity and abundant growth of its primitive mesoblast and in the apparently late formation of the yolk sac.

In Year Book No. 37 (1937-1938) Dr. Streeter pointed out the fact that when we examine progressively earlier and earlier pri-

mate embryos we finally get back to stages at which they resemble other mammalian embryos more and more closely. At the earliest stages, developmental phenomena are in large part common to all mammals. Against this important fact, Dr. Heuser's description of the chimpanzee ovum calls our attention to the opposite and perhaps equally important point that certain differences between closely related species can be perceived even at the 11th day of development. Since we already know that the unsegmented eggs of various mammals are distinguishable by slight differences, we may suppose that the different species are never quite alike in their morphology.

VOLUMETRIC ANALYSIS OF YOUNG EMBRYOS

The rate of growth of the human organism as a whole has been studied quite thoroughly from the fetal stage on to maturity. Not only have changes in weight and general dimensions of the whole body been followed in this way, but also the weights of individual organs and the changes in their sizes and weights relative to each other and to the whole body. Such studies, however, have not been carried back into the embryonic period. Little information is available concerning the exact proportion of parts in embryos younger than the second lunar month. This lacuna is due partly to the inapplicability of usual methods of measurement to younger embryos, for obviously a specimen no bigger than a grain of millet seed, which has been sectioned and mounted on slides, cannot be measured and analyzed directly with calipers and a chemical balance. It is also due to a lack of suitable material, for it is necessary to make use of embryos obtained in the uterus and sectioned *in situ*, in order to obtain the volume of an

embryo and its parts in terms of the fetal membranes that support it.

Dr. E. A. Boyden, of the University of Minnesota, having readily available a 12-somite embryo of suitable character (the Litzenberg embryo), has undertaken a volumetric analysis. The basic method of the study was Hammar's paper-weight method, by which sections of the embryo are magnified and projected optically onto paper of uniform thickness. The desired regions or organs are traced and the traced areas cut out and weighed. To this laborious method Dr. Boyden has applied much ingenuity of analysis and comparison. Since the Litzenberg embryo lacks the yolk sac and is injured in the mid-gut region, Boyden has supplemented it with a similar study of the 10-somite Corner embryo, a specimen which is relatively perfect internally and well preserved, but was not sectioned *in situ* and hence lacks the fetal membranes.

These two specimens, incidentally, illustrate the value of the policy of broad cooperation which has characterized Dr. Streeter's directorship of this laboratory, for both of them were obtained by investigators in other cities, but both were studied (the Corner embryo in particular) in consultation with the Department and with the aid of its technical staff, and both were depicted by Mr. Didusch.

The two specimens represent about one day of development (approximately the 23d day). Among the findings of general interest the following may be cited:

1. The trophoblast of the Litzenberg embryo is 380 times the tissue of the embryo; the intervillous space, 640 times. The actual surface of the villi (through which nutritive substances pass from mother to embryo), computed on the basis of a membrane 20 microns thick, would cover an area about 2 m. square, giving an area of 12,340 sq. mm. for every cubic millimeter of embryo. The relation, similarly expressed, of placental surface to fetal weight at term has been estimated at about 3:1 to 6:1.

2. As further indication of the great amount of accessory tissues required to sup-

port and nourish the embryo during its early period of rapid relative growth, we learn from Boyden that while the absolute volume of the Litzenberg embryo (deducting all cavities) is 0.2 cu. mm., the implantation cavity (combined chorionic vesicle and intervillous space) is 295 cu. mm., i.e., 1300 times the embryo proper, 1400 times the tissue of the embryo, and 675 times the embryo and its contiguous membranes (yolk sac, amnion, and umbilical cord).

3. The contractile myocardium of the Litzenberg embryo forms 1/19 of the tissues of the embryo, but only 1/13,800 of the fetal tissues which are to be supplied with blood (i.e., embryo, body stalk, yolk-sac wall, amnion, and chorion). This is an extremely low proportion of heart tissue to tissues supplied with blood (in the adult human body the heart is required to supply only 200 times its own weight) and can only be explained on the assumption that at this early stage, when the blood is just beginning to circulate, the fetal membranes are getting much of their nutrient material and carrying on their respiratory gas exchange and their metabolic excretion processes by direct diffusion to and from the body fluids.

4. The brain is 1/13 (Corner embryo) to 1/10 (Litzenberg embryo) of the tissues of the embryo. At birth the ratio is 1:10 to 1:8, and in the adult 1:42 (males) and 1:40 (females).

5. In the Litzenberg embryo the brain is larger in proportion to the whole body than in the slightly younger Corner specimen, whereas the ratio of spinal cord to body is the same. This hints that even as early as the 4th week the brain is growing faster than the spinal cord.

DEVELOPMENT OF THE ADRENAL CORTEX IN MAN

Dr. Unto U. Uotila, Rockefeller Fellow in the Department of Anatomy at Harvard Medical School, has reinvestigated the development of the adrenal cortex in man. For this purpose he visited the laboratory of the Department of Embryology, where 36 human

and 3 monkey embryos were put at his disposal. His observations agree in the first place with the generally accepted theory regarding the origin of the primordial fetal adrenal cortex from proliferating coelomic mesothelium. There has been a difference of opinion as to the subsequent differentiation of the permanent cortex. Dr. Uotila's findings confirm the view that the permanent cortex does not arise from the fetal cortex, but comes from a second proliferation of mesothelial cells which occurs at the age of 6 to 6½ weeks. The new elements come into contact with the ventral surface of the fetal cortex, where there is no investing capsule, and spread over the surface of the gland. The cells of the fetal and permanent cortex are cytologically distinct from the time of their earliest differentiation.

DEVELOPMENT OF GONAD, ADRENAL CORTEX, AND MÜLLERIAN DUCT IN THE ALLIGATOR

Dr. Thomas R. Forbes, of the Department of Anatomy of the Johns Hopkins University, has continued his studies of the reproductive system of *Alligator mississippiensis*. The development of the gonads before hatching agrees in general with that in other reptiles. The alligator, like the turtle, differs from

higher vertebrates in that the embryonic gonad retains for a relatively long time the bisexual traits characteristic of early embryos; that is, until late stages the cortex and medulla are both present and well defined. Dr. Forbes finds further evidences of bisexuality in juvenile stages, namely the retention by immature females of Wolffian ducts and testis-like medullary tissue, and the persistence in immature males of cortical areas and Müllerian duct segments.

In the embryos and young post-hatching stages studied by Dr. Forbes no interstitial tissue was found in the testis. Whether this is a permanent condition must be settled by study of the testes of adult alligators. The occurrence of interstitial tissue in the reptilian testis seems to vary greatly from species to species.

The primitive adrenal cortex is derived from the coelomic epithelium in continuity with the primordial genital gland. The two proliferations, of the adrenal and the gonad, begin at the same time and have a marked histological resemblance. This fact is important in connection with the chemical resemblance of the adrenal hormone to those of the gonads and the widely accepted view that under certain conditions the adrenal cortex can produce androgenic hormone.

PLACENTATION AND PLACENTAL FUNCTION

PERMEABILITY OF THE PLACENTA

It is hardly necessary to point out the importance for embryology of understanding the mechanism of transfer of substances across the placenta from the blood of the mother to that of the embryo and vice versa. Dr. Louis B. Flexner, in collaboration with Dr. Richard B. Roberts, has begun to investigate the possibility of studying placental permeability by use of radioactive isotopes ("tracer elements"). In particular, the first experiments were planned to test the possibility that differences in size of litter mates are dependent upon differences in the rate of passage of substances from the maternal blood to the fetus. Radioactive sodium was therefore used

to measure the permeability of the placentas of different members of a litter, the relative rates of transfer of the salt being then compared with the mass of the individual litter mates.

Radioactive sodium (Na^{24}) was prepared in the form of sodium chloride by use of the electrostatic pressure generator of the Department of Terrestrial Magnetism. It was dissolved in water and injected into the blood stream of the pregnant cat. The fetuses (removed under anesthesia at a suitable time after the injection) and blood samples from the mother having been ashed, the radioactivity of the ashed remains was measured with a pressure ionization chamber. Five

litters were studied. The resulting figures show a fairly high inverse correlation between total fetal mass and content of radioactive sodium per unit weight; that is, each fetus of a litter, whether large or small, has received through the placenta approximately the same absolute amount of the tracer salt. So far as can be judged from this study made during

the last 4 days of gestation, weight of the fetus is not related to difference in permeability of the placenta to sodium chloride.

More important even than this particular finding is the demonstration of usefulness and practicability of the radioactive tracer elements. Dr. Flexner is continuing their use in similar problems.

PHYSIOLOGY OF THE REPRODUCTIVE SYSTEM

In a symposium at the December 1939 meeting of the American Association of Anatomists Dr. Hartman presented a survey of the studies on the physiology of reproduction in the monkey which have been carried on by himself and associates for many years. The great additions to our knowledge won for us by this work have all been reported by Dr. Streeter in the successive Year Books, and need not be repeated here; but Dr. Hartman's résumé calls attention very forcefully not only to what has been gained already, but also to the possibilities of further advance in understanding of human reproduction through continued study of the monkeys and anthropoid apes.

BREEDING SEASON OF THE MUSKRAT

Dr. Thomas R. Forbes, in collaboration with Dr. R. K. Enders, of Swarthmore College, has made a study (under the auspices of the U. S. Biological Service) of the time of the breeding season of the muskrat. This has not been well understood and probably varies in different parts of the United States. Examination of the ovaries of 119 muskrats, trapped from November through March at the Blackwater Migratory Bird Refuge on the Eastern Shore of Maryland, revealed evidences of ovulation (i.e., the presence of recent corpora lutea) in January, February, and March. By comparison of histological appearances, Forbes and Enders came to the conclusion that the first ovulatory cycle of the annual breeding period occurred during the early part of February and the middle of March, and that a second ovulatory cycle subsequently appeared. Such studies, though primarily of importance to breeders of fur-

bearing animals, add also to our accumulating general knowledge of reproduction in mammals.

MENSTRUATION IN INTRAOCCULAR TRANSPLANTS OF THE ENDOMETRIUM

In Year Book No. 37 reference was made to the work of Dr. J. E. Markee, whose studies on menstruation, made chiefly at Stanford University, were carried on in our laboratory during the year 1935-1936. Although Dr. Markee had kept his colleagues aware of the general nature of his work by reports at scientific meetings, there was no comprehensive account previous to the monograph which appears in the current "Contributions to Embryology."

Dr. Markee has utilized a new method of studying the phenomenon of menstruation by implanting small pieces of the lining of the uterus (endometrium) into the anterior chamber of the eye. Here they take root, are nourished by blood vessels which grow into them from the iris, and can be observed with moderate powers of the microscope, through the transparent cornea. In such grafts, menstrual bleeding occurs much as it does in the uterus and follows the same cycle. As in the uterus, so in the intraocular grafts the endometrium goes through a cycle of alternating growth and regression. Markee finds that when regression is rapid, it is followed by menstrual bleeding. In this process the coiled arteries of the endometrium are especially involved; as the transplants diminish in the phase of retrogression, there is first a period of stasis of blood in the region supplied by the coiled arteries, and then a period of constriction of the arteries. The tissue which

they supply is thus left bloodless for several hours. The arteries then relax, the blood flow is resumed, and blood escapes from the arterioles, capillaries, or veins. The small quantities of blood thus freed into the tissue escape from the grafts in various ways, described in detail by Markee.

An important conclusion from these observations is that the process is much the same in anovulatory as in ovulatory menstruation.

Dr. Markee did a good many experiments with the ovarian hormones estrone and progesterone, and with the male hormones androsterone and testosterone, especially during his year in Baltimore, when he had the active cooperation of Dr. Hartman. Among his many findings we may note the following. A course of estrone, sharply discontinued (causing a state of estrone deprivation), gave rise to menstruation-like bleeding in the grafts, as we should expect from previous experiments. By gradual withdrawal of estrone, however, it was possible to induce slow retrogression of the endometrium, as verified by direct observation of the grafts. Menstruation then did not occur. Menstruation which occurred during and in spite of ample daily injections of estrone was preceded by regression of the endometrium. The injection of estrone during menstruation did not alter the sequence of events. The bleeding produced by estrone deprivation and progesterone deprivation is similar to normal menstruation, a very important point for the theory of menstruation.

By inserting crystalline estrone into an eye in which a graft was present, and by subsequent removal of the hormone, it was possible in a series of experiments either to raise or to lower at will the concentration of estrone acting locally upon the graft in the same eye relative to that acting on a graft in the other eye via the general blood stream. The results showed that the rate of regression of the graft, and the occurrence or nonoccurrence of bleeding, are under control of hormone acting locally (i.e., directly) on the graft.

Dr. Markee concludes that in all probability menstrual bleeding is the result of

rapid regression of the endometrium and the immediate cause of the bleeding must be looked for within the frame of that process.

PROGESTERONE NOT EXCRETED AS PREGNANE-DIOL IN THE MONKEY

The discovery about three years ago by Venning and Browne, of Montreal, that in the human female the corpus luteum hormone, progesterone, is excreted as pregnanediol, conjugated with glycuronic acid, has already been of great value in studies of corpus luteum function in the menstrual cycle and in pregnancy, both normal and abnormal. By measuring the amount of pregnanediol glycuronidate in the urine, at least a rough determination of the activity of the corpus luteum may be obtained. Inasmuch as the rhesus monkey has come to be the standard primate animal for the study of menstrual phenomena and of pregnancy, there have been several attempts, published and unpublished, to identify pregnanediol in monkey urine. These have yielded negative results.

Dr. Carl G. Hartman therefore joined forces with a biochemist of great experience with the steroid hormones, Professor R. E. Marker, of Pennsylvania State College, to obtain a more complete assay of pregnancy urine of the monkey for various steroid compounds. Professor Marker was supplied first with 12 gallons of urine from 3 pregnant animals. The assays showed no trace of the pregnanediols common to pregnancy urines of several other species including man. When progesterone was administered to a pregnant monkey in a large amount (more than 1 g. in 20 days) pregnanediols did not appear in the urine. The progesterone had no unfavorable effect on either the mother or the fetus.

We remain therefore in ignorance as to the steps by which progesterone is metabolized in the monkey, and as to the nature of its excretionary end products.

A pregnant monkey which received more than 1 g. of estrone in 20 days (which caused the death of the fetus) yielded only a very small portion of the total estrone injected.

EFFECT OF TESTOSTERONE UPON THE UTERUS OF THE MONKEY

Dr. C. G. Hartman has reported his experiences with the administration of steroid hormones in pellets inserted under the skin by the method devised by Deanesly. The method is especially useful when the effects of small amounts of hormone over long periods of time are desired. Hartman reports physiological effects in a monkey during 4 months from a single 3-mg. pellet of estrone.

Eighteen experiments were performed to determine the effect of the male hormone testosterone upon the monkey's endometrium. In general, testosterone did not exert an action resembling that of progesterone; a pregestational endometrium, with serrated secretory glands, was never attained with testosterone alone or in combination with estrogens. On the other hand, no evidence was found for any antagonistic action of testosterone against either estrogen or progesterone when concomitantly injected with one or both of these hormones. Testosterone, however, reddens the sex skin like an estrogen and is able to maintain an endometrium already built up by an estrogen.

Among the well known effects of the corpus luteum hormone is that of inhibiting the menstruation-like bleeding which follows withdrawal of estrogens. The male hormone testosterone and its acetic and propionic esters produce the same effect. Dr. A. R. Abarbanel finds that a similar action is exerted by injection of the dipropionic ester and also by methyl-testosterone and ethinyl-testosterone (pregnenolone), and reports partial success in eliciting the same action when testosterone propionate (given with bile salts) and methyl- and ethinyl-testosterone were given by mouth. The latter drug has already appeared in the drug trade as a substance having progesterone-like action (as determined by another test) when given by mouth. In Dr. Abarbanel's experiments it prevented estrin-deprivation bleeding when given by injection in doses of 5 mg. daily. By mouth, it delayed but did not prevent bleeding in doses of 20 mg. daily. As judged by this result, ethinyl-testosterone

is not a very effective or economical oral substitute for progesterone.

GONADAL HORMONES IN REPTILES

Dr. T. R. Forbes has continued his observations on the effects of gonadal hormones in reptiles, studying a number of young alligators which received injections of the male hormone testosterone propionate. The oviducts of the injected females showed a uniform and marked development and growth, and the phallic organs of both sexes (penes and clitorides) were strikingly hypertrophic. The mesonephroi and mesonephric ducts were not affected in either sex. Histological findings suggested some influence of the hormone on the gonads, but the evidence was not conclusive.

Adult male lizards of the genus *Sceloporus* reacted vigorously to the implantation of pellets of testosterone and of estrone. The male hormone caused hypertrophy of the male accessory organs and stimulated spermatogenesis. Estrone prevented spermatogenesis, caused atrophy of the testes, and reduced the size of the epididymides.

STIMULATION OF CELL DIVISION IN MALE ORGANS BY ESTROGENS

It is well known that the estrogens or so-called female sex hormones produce effects on the male reproductive system, inducing, for example, changes in the epithelium and increase of the fibromuscular stroma of the prostate gland. After longer treatment similar effects are produced in the seminal vesicles and the more distal parts of the genitourinary canal. There is some evidence that mitotic division, presumably induced by direct action of the hormone, is a factor in producing the epithelial changes, but the hyperplastic fibromuscular stroma of the prostate has not as yet been observed to contain mitotic divisions. Mr. Richard Tislowitz, of the Johns Hopkins Medical School, at Dr. Hartman's suggestion has applied to this problem the colchicine technique by which mitotic divisions are arrested and accumulated. Mitotic figures were readily found in the fibromuscular

stroma. An artificial estrogen, diethyl-stilboestrol, produced changes in the prostate and seminal vesicles similar to those induced by estrogens of steroid structure.

PENETRABILITY OF MUCUS IN THE CERVIX UTERI BY SPERMATOZOA

Recent studies have indicated that the mucus of the human uterine cervix, through which spermatozoa must pass in order to fertilize the ovum, may vary in its penetrability, and even that such a variation may occur normally as a feature of the female reproductive cycle. Dr. J. K. Lamar, working in the Department as a fellow of the National Committee on Maternal Health in collaboration with two workers in the Department of Obstetrics of the Johns Hopkins University, namely L. B. Shettles (on a similar fellowship) and Eleanor Delfs (a fellow of E. R. Squibb and Sons), has applied to this problem a simple and satisfactory method devised by himself, in which the passage of spermatozoa through a sample of mucus in a capillary glass tube is watched and timed under the microscope. The results confirmed the statement, made by Séguay and Vimeux in 1933, that there is a cyclic production of a special type of cervical mucus at about mid-cycle, which renders the cervix temporarily penetrable by spermatozoa. The spread of this phase in the cycle is roughly from day 9 through day 19, although for any one cycle the period of penetrability may be restricted to about 4 days. This period coincides with the period of lowest number of leucocytes in the mucus, of the highest pH (disregarding the period of menstrual flow), the largest amount of mucus secreted, and the height of conditions favoring longevity of spermatozoa in the mucus. The relation between penetrability and viscosity of the mucus is not clear.

Indications are that the menstrual discharge is penetrable by spermatozoa, but the mucus of the phase between menstruation and the mid-cycle is relatively impenetrable,

and that of the phase between mid-cycle and the subsequent menstruation is quite impenetrable. The authors urge the application of the microtube method, and the facts they have ascertained with it, to the investigation of otherwise unexplained cases of sterility.

HORMONES AND MATING BEHAVIOR

Following up a study of sex behavior of rats under stimulation with estrogenic hormones, reported in Year Book No. 37, Dr. Josephine Ball observed the sex behavior of male rats castrated at weaning and treated with estrogens during the following 1½ to 3 months, and compared it with that of similarly treated female litter mates and of normal brothers and sisters. All the castrates, male and female, showed part of the typical female estrous behavior (copulatory lordosis), but the rest of the pattern was seldom elicited, never in males. Four of six male castrates copulated like males to a limited extent. None of the females showed any masculine tendencies.

The experiment suggests that the neuromuscular pattern underlying male copulatory behavior is organized very early, possibly even before birth, and that the hormones of puberty act by lowering the threshold of this activity, not by organizing it.

Dr. Ball has also investigated the effect of the male hormone testosterone on the sex behavior of young adult female rats. After fairly large doses during 2 months, eight to ten rats continued to accept the males even though signs of the female cycle were repressed. At the same time the treated female rats also exhibited male sex behavior to a considerable degree. Untreated females exhibit male copulatory behavior under the influence of certain special stimuli. It is concluded that the male copulatory pattern in more or less rudimentary form is part of the equipment of the normal female rat. The threshold of this behavior pattern is normally very high but it can be lowered by treatment with the male hormone.

ENDOCRINE ORGANS

ACTIVITY OF THE ADRENAL CORTEX

We are greatly in need of methods by which the physiological activity of glands of internal secretion can be related to the structure of these glands as seen under the microscope. Dr. Louis B. Flexner, in collaboration with Dr. Arthur Grollman, of the Department of Pharmacology of the Johns Hopkins Medical School, has studied the adrenal cortex of the rat, making use of the fact that the cortical cells contain substances which reduce osmium tetroxide and thus give visible evidence of their activity by black deposits of the lower oxides of osmium. Dr. Flexner and Dr. Grollman have subjected rats to experimental conditions known to depress or to stimulate the physiological activity of the adrenal gland. If, for example, the animals are supplied with cortical hormone by injection, these glands are not called on to produce as much hormone as normally. In this circumstance the investigators found a diminished reduction of osmium tetroxide in the adrenal cortex. When, on the other hand, the output of cortical hormone was stimulated by subjecting the rats to extremes of temperature, or when one adrenal was made to secrete more actively by removing the other, Dr. Flexner and Dr. Grollman found an increased reduction of osmium tetroxide by the cells of the adrenal cortex. Increased reduction was also produced by inanition and by the injection of tetrahydro- β -naphthylamine, which is a sympathetic stimulant, and by the thyrotropic hormone of the pituitary gland.

The changes in reducing power of the cells thus produced are not to be taken as a direct measure of the presence or quantity of cortical hormone, but rather, no doubt, as evidence of altered metabolic states associated with endocrine activity. The reducing substances are of several kinds, including unsaturated lipids, various steroids including the cortical hormone, and compounds such as ascorbic acid and glutathione.

The authors point out that their results cannot as yet be transferred to other species; in

studying the rat they have had the advantage of a highly standardized species.

X-ZONE OF THE ADRENAL

One of the many puzzling questions afforded by the adrenal gland is that of the nature and function of the so-called X-zone of the adrenal cortex. This occurs in mice, and has not been clearly identified in other mammals. It is a zone of cells at the inner side of the cortex, between the zona fasciculata and the medulla. First recognizable in the second week of intra-uterine life, it soon degenerates in the male, but in the unmated female persists throughout the reproductive period. During pregnancy it degenerates. Dr. I. Gersh of the Department of Anatomy and Dr. A. Grollman of the Department of Pharmacology of the Johns Hopkins Medical School, following up certain older observations, find that when the immature or castrate mouse is given thyroid powder, and thus caused to need adrenal cortical hormone, there is a pronounced hypertrophy of the X-zone. Administration of cortical hormone, on the contrary, causes degeneration of the X-zone, and large doses given to very young animals may inhibit its appearance. It has been observed that in animals which do not have an X-zone similar effects occur in true cortical tissue. The interpretation is that the X-zone performs the same function as the other cortical zones of the adrenal, and that the X-zone acts as a reserve tissue which can be called out in case of need for more cortical hormone, but subsides when the need does not exist or is satisfied in some other way.

PROTEIN AND IODINE IN THYROID TISSUES

At the 1940 meeting of the American Association of Anatomists, Dr. Gersh described his studies of the thyroid gland by application of the ultraviolet microscope to frozen-dried sections. It was possible to determine the concentrations, in colloid, cytoplasm, and nuclei, of thyroglobulin, protein-bound iodine, and cyclic components of protein (tyrosine plus tryptophane). The conclusions will be reviewed in a subsequent Year Book.

TISSUE CULTURE AND TUMOR STUDIES

As a participant in a symposium of the Association for the Study of Growth, Dr. Warren H. Lewis has reviewed some of the contributions of the tissue-culture method to the study of development and growth. Although he was able to refer to important additions to our knowledge of cell types and cell behavior, many of them achieved by himself and his co-workers, Dr. Lewis makes it clear that with respect to the broad field of growth and differentiation we can claim only that the study of tissue cultures has helped to define the problems. In the long run we shall need to attack them with a combination of morphological methods and organic and physical chemistry. In this phase of progress the techniques of tissue culture will doubtless be highly useful.

THE CHROMOSOMAL NATURE OF NUCLEOLI

It has become known during the past decade that the nucleoli of animal cells are in certain lower animals associated with definite regions of particular chromosomes. Dr. W. H. Lewis has examined his motion pictures of normal dividing rat fibroblasts in tissue cultures to see whether in these mammalian cells there is any sign of a similar relation. Dr. Lewis finds that when in the process of mitotic division the chromosomes are just attaining their maximum visibility and number, each of the larger nucleolar masses splits into two or more bodies of the same size and appearance as the chromosomes. The smaller nucleoli remain unbroken and assume the appearance of chromosomes. When chromosomal movements begin, leading up to their arrangement on the metaphase plate, it becomes impossible to follow any longer the separate fate of those chromosomes that came, or seemed to come, from the nucleoli. After formation of the daughter cells some of the chromosomal particles persist as nucleoli. Dr. Lewis concludes that in rat fibroblasts the nucleoli consist of chromosome material.

Dr. Lewis exhibited some of his motion pictures of dividing fibroblasts, upon which

the above observations are based, at the 1940 meeting of the American Association of Anatomists. The pictures indicate that the mechanics of cell division involves a series of changes in viscosity of the superficial plasmagel layer.

TISSUE CULTURE OF OVARIAN EPITHELIUM

Although ovarian tissues have been cultivated *in vitro*, the germinal epithelium has not been grown. Dr. J. Herman Long, using the technical procedures developed by Dr. W. H. Lewis, Dr. M. R. Lewis, and Dr. G. O. Gey, has now obtained and photographed an abundant growth of germinal epithelium from the ovary of the mouse in roller-tube culture. The most important feature of the observations was the appearance of primordial follicles and of ova in the layer of newly formed epithelial cells. The ova grew to a size comparable with that of similar cells arising naturally in the ovary. The observation has an important bearing on the question as to whether, in the normal mammalian ovary, ova are formed after birth. The mouse is the animal in which such neof ormation of ova has been most plausibly described. Culture of the germinal epithelium of other species is much to be desired.

MUSCLE CELLS IN DIBENZANTHRAcENE
MOUSE SARCOMAS

The injection of dibenzanthracene into mice gives rise to malignant tumors originating from connective tissues. Dr. Warren H. Lewis has studied the histology of 50 such sarcomatous tumors in pure-strain mice. The point of greatest interest is that 22 of the tumors contained modified skeletal muscle fibers, muscle giant cells, and myoblasts. Some of them had so much muscle that they would probably be diagnosed as rhabdomyosarcomas. As the tumors were carried on by transplantations to other mice, the muscle cells grew less and less in number until in later generations they disappeared. The changes of the muscle cells and their deriva-

tives seem to be those of dedifferentiation. These observations offer a suggestion as to the nature of human malignant tumors containing muscle cells or myoblasts (rhabdomyosarcomas and myoblastomas). Dr. Lewis points out that in these tumors, as in those of the experimental mouse, the muscle elements are probably in process of dedifferentiation into myoblasts and spindle cells. The large percentage of such tumors produced in rats and mice by carcinogenic agents, as compared with those occurring spontaneously in man, may be explained by the longer duration of the latter, giving an opportunity for any modified muscle originally present to degenerate into spindle cells. The great variations in the histology of rhabdomyosarcomas and rhabdomyoblastomas, both human and animal, can likewise be attributed to the changing character of the muscle elements.

BIOLOGICAL DIFFERENCES IN INDUCED SARCOMAS

A study of the transplantability of sarcomatous tumors induced by dibenzanthracene, made by Dr. M. R. Lewis and Mrs. E. G. Lichtenstein, was reported in Year Book No. 37. In continuation of this study, the investigators have found six-spindle-cell sarcomas that had an inherent power to grow when transplanted into mice of pure inbred strains other than those in which the tumor originated. The six tumors all looked alike under the microscope, and grew alike in mice of their own strain; but when transplanted into alien strains they exhibited striking differences in growth energy. Another means of observing differences between the tumors was afforded by the fact that when implanted in mice of alien strains they did not grow sufficiently to kill the host mice, but regressed. The mice in which a sarcoma had grown and regressed proved to have become resistant to another tumor graft of that tumor but not necessarily to the other five tumors. The existence and persistence of such pronounced differences between tumors of similar pathological type, presumably originating from similar tissues as the result of an identical stimulus, is quite remarkable.

METABOLISM OF SARCOMA CELLS IN TISSUE CULTURE

Because of the unrestrained growth of cells of malignant tumors, a great deal of interest attaches to their metabolism and there have been many efforts to determine the extent to which their respiration and consumption of foodstuffs differ from similar activities of normal cells. Slices of tumor material have generally been used for such studies. Dr. C. L. Gemmill and Mr. R. Austrian, of the Johns Hopkins Medical School, and Dr. G. O. Gey have now devised means by which cells growing in tissue culture may readily be studied in the same way. By the roller-tube culture method an adequate amount of material is made available, and this is observed in a specially designed metabolism chamber provided with an all-glass pump.

An investigation has been made of the oxygen consumption, utilization of glucose, lactate production, and metabolism of urea and nonprotein nitrogen of a well-known pure strain of malignant cells (Walker rat sarcoma 319). This tumor grows fairly rapidly in culture; the explants doubled their volume in about 40 days. The oxygen consumption averaged 4.5 cu. mm. per milligram of tissue per hour. There was no evidence of accumulation of lactate in the culture medium, an observation which does not agree with the generalization made on the basis of Warburg's work, that tumor tissue characteristically has deficient respiration, so that intermediate metabolites are not oxidized and lactate accumulates. The Walker sarcoma 319 may therefore be added to the list of tumors which do not have a high aerobic glycolysis.

The utilization of glucose by the cultures is very rapid, so rapid indeed as to indicate that glucose is used for other purposes besides oxidation. Since there is no lactate formation, the glucose may be stored. The nonprotein nitrogen in the culture medium increased after contact with the tumor cells. Urea did not increase, and in all probability the change in nonprotein nitrogen was due to accumulation of ammonia or amino acids produced by digestion of the proteins in the culture medium by the cells.

DIFFERENTIATION OF MYELOBLASTS FROM LYMPHOBLASTS

At the very heart of our current uncertainties as to the relationship of the blood- and blood-forming cells lies the question of the identity or nonidentity of the lymphoblasts and myeloblasts, large immature cells with basophilic nongranular cytoplasm which are found in the bone marrow and the lymphoid tissue, and from which (in these respective situations) the granular leucocytes and the lymphocytes develop. In fixed and stained preparations these two cells look so much alike that workers of one school believe them identical, while others believe that they may be distinguished from each other by slight differences of structure, admittedly difficult to detect. Dr. Margaret R. Lewis, with Dr. A. R. Rich of the Department of Pathology and Dr. M. M. Wintrobe of the Department of Medicine of the Johns Hopkins Medical School, has studied these cells in hanging-drop tissue cultures and has recorded their movement in motion pictures. Myeloblasts were obtained from normal marrow and from leukemic blood, and lymphoblasts from normal lymph nodes and from leukemic blood. A striking difference in the manner of locomotion was revealed. In such cultures cells of both types move freely. The lymphoblasts proceed steadily, retaining a persistent broad anterior end which bears a few pseudopodia, and a rigid tail-like process at the rear. The cell has therefore a characteristic outline resembling a hand mirror. The picture is similar to that of the lymphocyte, as described earlier by Dr. W. H. Lewis. The myeloblasts, on the other hand, assume the form of a twisted cylinder and move in a writhing, wormlike manner. The leading and following ends of the cell remain fixed for considerable periods of time, but the direction of motion may be suddenly reversed. The leading end bears a few pseudopodia. Monocytes show the characteristic large pseudopodia bordered by undulating membranes,

which the motion pictures of W. H. Lewis have made familiar. M. R. Lewis, Rich, and Wintrobe regard their findings as evidence against the view that lymphoblasts and myeloblasts are identical.

The authors have also applied the same method to large mononuclear cells which appear in great numbers in the spleen when it is enlarged during infection—the so-called acute splenic tumor cells. They find that in tissue cultures these cells exhibit the type of motion characteristic of the lymphoblast, and conclude that they are lymphoid in character. It was found incidentally that infection is not necessary for the production of acute splenic tumor, for the same condition may be produced by injection of foreign proteins. A lymph node draining infected tissues or a region into which foreign protein has been injected exhibits lymphoid cell proliferation like that characteristic of splenic tumor. It appears, therefore, that the lymphocyte is in some way functionally concerned with the reaction of the body to foreign protein.

VIRUS OF LYMPHOPATHIA VENEREUM

Dr. Gey, with Dr. F. B. Bang, of the Johns Hopkins Department of Pathology, has been able to infect tissue cultures of human fibroblasts with the virus of lymphopathia venereum. The investigators have been able to follow in the living cells the development of the peculiar intracellular vesicles containing granular corpuscles which are characteristic of tissues infected with this disease. They found that under conditions not clearly understood the vesicular reaction of the cells may disappear completely, yet the virus persists in the tissue culture. Because of reports concerning the efficacy of sulfanilamide in the treatment of this infection, the drug was added, in low concentration, to the culture medium. The vesicles disappeared, but the experiment was not conclusive as to the effect on virulence.

MORPHOLOGICAL STUDIES

GROWTH AND DEVELOPMENT OF THE CHIMPANZEE

In a comprehensive monograph Dr. A. H. Schultz has summed up the results of many years' study of the growth of the chimpanzee. The material used consists of several living animals studied during many years, of over 100 preserved or fresh bodies from fetal to adult life, and 90 complete and incomplete skeletal specimens. The material has been obtained from many sources, in particular through the generous aid of the Yale Laboratories of Primate Biology.

In the chimpanzee, infancy lasts about 3 years and adulthood is reached early in the 11th year. During prenatal life the chimpanzee follows the curves of growth of man until about the end of the 7th lunar month, after which it gains in size much more slowly than the human fetus. At birth the chimpanzee is much smaller than man, averaging less than 1600 g. weight. The cranial capacity attains its full size at 6 years. This rapid growth of the brain and comparatively early cessation of growth are found in other primates except man. The face grows much more rapidly than the brain part of the head, and in general the chimpanzee head, strikingly similar to the human in fetal life, becomes more and more brutish as the animal grows older. The orbits move forward from a position underneath the brain until they are mostly in front of the brain.

Skin pigmentation develops much earlier than in the colored races of man. The deciduous teeth erupt between the ages of 2.5 and 14.5 months. The canine teeth are the last to erupt, a condition which occurs also in fossil man, although this sequence of eruption is much altered in recent man. The permanent teeth erupt, on the average, between the ages of about 3 and 10 years. Here again the order of eruption resembles that of fossil man but not of modern man.

Dr. Schultz gives full details of the measurements of the skeleton, the development of centers of ossification, and the times of closure of the epiphyses of the limb bones and

of the fontanelles and sutures of the skull. He emphasizes the considerable variability which he has found.

THE SIZE OF THE ORBIT AND OF THE EYE IN PRIMATES

Dr. A. H. Schultz has studied the relations between the body weight, the capacity of the orbit, and the size of the eye in 208 primates representing all major groups and widely differing ages. Weight and orbital capacity alone have been studied in an additional 115 specimens, and the capacity of the orbit only in still another series of great apes and man, totaling 187 more specimens.

The absolute capacity of the orbit varies in recent, adult man between 16.5 and 31 cc., the average being approximately the same as the averages for chimpanzees and for orang-utans, but much smaller than the average for gorilla or for a few fossil men examined.

All the large primates have proportionately much smaller orbits than do the small primates. The relative capacity of the orbit is somewhat greater in females than in males and very much greater in young than in adult specimens. Among animals of the same species and age the largest individuals have proportionately the smallest orbits. From these varied findings it is evident that the relative capacity of the orbit is largely dependent upon body size regardless of genus, sex, or age. Only in some nocturnal primates have the orbits attained exceptional relative size. The relative capacity of the orbit in recent man is the second lowest among all primates, the minimum value occurring in female orang-utans. It seems, however, that this index was much higher in fossil man.

The relative size of the eyeball varies in adult primates between 0.006 in male orang-utans and 2.243 in a female tarsier; that is, per unit of body weight the eye of the latter is 374 times larger than that of the former. The relative size of the eye of man stands very near the lowest value among adult primates. Females have proportionately larger eyes than males. The relative size of the eye

undergoes very profound changes during growth, becoming rapidly smaller in all the primates studied.

The relative volume of the eye, even more than the relative capacity of the orbit, stands in a remarkably regular inverse ratio to body size, regardless of genus, sex, or age. The relative size of the eye diminishes rapidly with an increase in body weight up to about 7 kg. Further increase in weight is accompanied by a less intensive, but still consistent decrease in the proportionate volume of the eyeball. Only the nocturnal primates (except the potto) form an exception to this rule by having unusually large eyes in proportion to their body weight.

The percentage relation between the volume of the eye and the capacity of the orbit varies among adult primates between 17 in orang-utans and 179 in the tarsier. Man, with an index of 32, stands, in regard to this proportion, between the great apes and the majority of the Old World monkeys. This eye-orbit index is always larger in females than in males and very much larger in young than in adult specimens. Females, therefore, have larger eyes than males and infants much larger eyes than adults not only in relation to body weight, but also in proportion to the size of the orbits. In all fetuses and newborns

studied the eyeball is so large in relation to its socket that it projects markedly beyond the orbital rim and therefore exophthalmos is normal in the fetus.

Considering all the evidence, it appears that the size of the orbit is dependent upon the size of the eyeball in only the most general way and that the two structures can vary in size independently to a surprising extent.

ANATOMY OF THE INGUINAL REGION

Basing his statements on his long experience in comparative anatomy and in the medical dissecting room, Mr. A. Brazier Howell has summarized for the benefit of surgeons his views regarding the descriptive anatomy of the inguinal region. The paper, which cannot be summarized in brief compass, explains certain structures and peculiarities of this region in man for which no ready explanation is given by embryology or comparative anatomy (for example, the linea semicircularis and the thin lower portion of the posterior rectus sheath, the accessory internal oblique muscle, and even the inguinal ligament) as local variations in the arrangement and amount of connective tissue or muscle, arising from special stresses and strains, presumably phylogenetic as well as ontogenetic.

NERVOUS SYSTEM

ABSORPTION FROM THE SUBARACHNOID SPACE

Messrs. R. O. Scholz and E. M. Ralston have re-examined the pathway of absorption from the subarachnoid space, using an improvement upon the method introduced by Dr. Lewis H. Weed, by which one of the ingredients of the well-known Prussian blue reaction is introduced in solution into the subarachnoid space and then thrown down by addition of the other ingredients to render visible, by the presence of precipitated Prussian blue, whatever pathways the fluid may have taken. Because of the possibility that post-mortem diffusion may lead to false conclusions, Scholz and Ralston prepared the brains of dogs and cats used in their experiments by a modification of the Altmann-

Gersh method, freezing the tissues with liquid air and drying them in vacuo. The result showed that the nontoxic isotonic solution of sodium ferrocyanide which they introduced into the cerebrospinal fluid passed into the venous system by way of the arachnoid villi and the arachnoid veins. Individual villi showed far greater concentration of Prussian blue than did individual veins. The result agrees in general with the conclusions Weed drew from his experiments of 1914.

THE MATURATION OF "EXCITABILITY" IN THE PRECENTRAL GYRUS OF THE MONKEY

It goes without saying that there is an embryology of function as well as of form. Much of the work of this Department and its

associates has been devoted to tracing the development of functional activities of animal tissues and organs. Volume 28 of the "Contributions to Embryology" contains an important monograph of Dr. Marion Hines and Dr. E. P. Boynton, reporting the results of seven years' study of the development of function in the motor area (precentral gyrus of the brain) of the monkey.

The authors' conclusions can best be understood by first recalling that in the adult brain cortex of mammals there is a special region along the anterior side of the Sylvian fissure, the precentral gyrus, which is associated with movements of the skeletal muscles and is generally considered to preside (in a way by no means fully understood) over the initiation of voluntary movements. When small areas in this region of the brain are stimulated, for example with an electric current applied through a fine needle, the result is contraction of single muscles or small groups of muscles, causing discrete and well defined movements, such as extension of the leg, snarling movement of the lips, or flexion of the fingers. Dr. Hines calls such movements "idiokinetic." The cortical areas from which they may be elicited are arranged (as long ago described) in serial order in the precentral gyrus, the areas for the upper part of the body in the lower part of the gyrus and vice versa. When one side of the brain is stimulated, movements are elicited either on the opposite side of the body, or on the same side or both sides, according to the now well-known anatomical pattern of motor nerve tracts connecting the cortex to the spinal and medullary nuclei.

When Dr. Hines and Dr. Boynton stimulated the corresponding area in monkey fetuses from 66 to 125 days of gestation, the only movements elicited were of another type; they were less clearly defined, often involving fairly extensive muscle groups, and often representing or suggesting well-developed behavioral complexes such as bodily progression. These movements lack the clear topographical representation of the idiokinetic movements. They are designated as "holokinetic."

The first idiokinetic movements were elicited at 135 days. In fetuses from 135 days to term (162 days), points from which idiokinetic movements could be elicited were located in three distinct areas separated by areas containing insensitive ("silent") regions, holokinetic points, or "chalastic" points yielding muscular relaxation. After the first few weeks of extrauterine life a gradual encroachment of idiokinetic points upon the other areas occurred, the silent regions becoming reactive and holokinetic points giving place to idiokinetic points. This process of maturation continued until the adult type of topographical projection emerged. After birth the movements elicited by stimulation of the precentral gyrus at each stage of growth followed a definite pattern correlated with the type of posture, progression, and general behavior characteristic of the animal at the same stage. It is a noteworthy fact that certain complexly integrated muscular reactions ("use patterns") were elicited by electrical stimulation before the animal exhibited them spontaneously. This hints that in the nervous system anatomical connection precedes functional use.

The threshold of sensitivity to the electrical current became lower with age. The stability of a sensitive point, that is, the regularity with which a response can be obtained, increased with age. The stability of a point on the older cortices was demonstrated to be correlated with the frequency and intensity of the current used. The range of frequencies which elicited idiokinetic movements grew wider as the animals matured.

This summary of an extensive work naturally cannot do full justice to it; there is not only a wealth of detail which must be read for thorough understanding, but also much theoretical discussion that will undoubtedly receive full and interested attention from other investigators of cerebral function.

DEFECTIVE DEVELOPMENT OF THE CEREBRAL CORTEX

Those who study embryology cannot fail to be interested in abnormalities of the em-

bryo. Teratology is one of the most ancient subdivisions of biology, and its problems, whether they arise through human sympathy in the tragic circumstances attending congenital malformations, or through the impersonal hope of learning something more about normal development through the abnormal, have always fascinated the anatomists. The subject was a major interest of the founder of the Department of Embryology, Dr. Mall, and his two successors have each contributed personal investigations as well. A striking individual instance of malformation has been studied by Dr. P. A. M. F. Fitz-Gerald, of Dublin, while a guest worker in this Department. An infant of normal parents, born after normal pregnancy and an uncomplicated labor, failed to react to his surroundings after the fashion of normal babies, and did not display normal motor activities. He died at 8 months from an infection. At autopsy the only significant lesion was defective development of the cerebral cortex. The central area on both sides was smooth, owing to nondevelopment of the sulci; the central sulci were indicated only by shallow depressions, and the anterior opercula were undeveloped. The corpus callosum was well developed; the intermediate mass of the thalamus was absent. The brain stem and cerebellum were normal. There was no abnormality of the ventricular system. Dr. Fitz-Gerald points out that the defect represents essentially the retention of a fetal stage, yet development of the brain cannot be said to have ceased at any specific period. Rather, the chain of linked effects by which development of one region leads to growth in another, and thus to normal organization, must have been altered at a fairly early stage.

Dr. Fitz-Gerald's careful analysis of the histology of the cortex in this case shows that the statement, frequently made in connection with cases of macrogryria, that the cortex is abnormally thick and the subcortical white matter deficient, is not correct. His interpretation is that the cerebral wall is imperfectly differentiated, retaining fetal characteristics, and that cortex and subcortical white matter are not fully distinguishable.

DEVELOPMENT OF THE NEUROMUSCULAR SPINDLE

The ample supply of fresh human material available at the laboratory of the Department of Embryology has enabled Dr. Fidel Cuajunco, of the University of the Philippines, while a guest worker, to improve considerably our knowledge of the development of the neuromuscular spindles, the proprioceptive end organs of skeletal muscle. As early as 11 weeks of gestation he finds the first evidences of the impending development of spindles, namely, characteristic plexuses with dotlike granules, around myoblasts which do not as yet show any structural differences from the rest of the embryonic muscle cells. At 12 weeks a special grouping of nuclei about certain myoblasts indicates that these are to become the intrafusal fibers of spindles. The capsule appears at this time; the periaxial space is first seen at 14 weeks. By the 24th week the spindle has differentiated into fully adult character, except as to size.

PYRAMIDAL LESION IN THE MONKEY

The nerve fibers which descend from the cerebral cortex to the spinal cord, constituting the pyramidal or corticospinal tract, are obviously of very great importance in the motor activities of the body. Numerous efforts have been made to study their function by cutting them and observing whatever alterations of movement and posture may occur. Dr. Sarah S. Tower, of the Johns Hopkins Anatomical Laboratory, has studied ten monkeys in which she was able to produce complete unilateral sections of the pyramidal tracts and one in which there was a complete bilateral lesion.

In the animals with the unilateral lesion there occurred on the opposite side of the body, especially in the shoulder and hip regions, a weakness of muscular tone, of lesser degree than flaccid paralysis, described by Dr. Tower as hypotonic paresis. With this there is deficient initiation and execution of all performance by skeletal muscle, with elimination of the nonstereotyped component movements and absence of all discrete use of the digits. The reflexes are sluggish and weak.

As a result, there is diminished general use of the affected extremities. Initiative in movement is delegated to the normal side, but if the normal side is restrained the affected side can, with sufficiently strong excitation, be brought to act. Owing to the elimination of nonstereotyped components involving discrete use of the digits, corrective movements for unusual postures, and the ability to take accurate aim or to modify movement in the course of execution, the activity of the paretic side is reduced to a limited number of stereotyped performances, employed only when they are indispensable. Those most in use are maintenance of posture, including righting, orientation of the body as a whole, progression, reaching-grasping, scratching, striking, and kicking.

In the one animal which survived bilateral lesion, the effects on muscular tone, reflexes, and use were similar although they involved the axial musculature as well as that of the extremities. Whereas, however, the monkey with a unilateral lesion compensates by increased use of the normal side, employing the paretic side only in symmetrically patterned activities and in support, the monkey with the bilateral lesion was compelled to rely upon his cortical extrapyramidal motor mechanism. He therefore worked out by trial and error, as far as he could, a series of stereotyped performances, by which he was able to sit, stand, progress, and take food. The highly interesting details must be read in the original paper in order to appreciate them.

From these observations, Dr. Tower pictures the pyramidal tract as exerting, in the first place, a tonic activity, which contributes to the excitatory state in the spinal cord, supporting muscular tone, facilitating, reinforcing, steadyng, and moderating whatever tonic or phasic activity may be set in action at segmental or suprasegmental levels. In the second place, the pyramidal tract initiates movement or speeds initiation, entering into all complex somatic motor activity to confer upon the stereotyped extrapyramidal performances all those modifications of pattern and adjustments in execution which make for aim, accuracy, economy, lability, and finish.

Although a considerable capacity for voluntary movement survives pyramidal section, especially if the lesion is bilateral, yet for the more labile, more discriminating, and more minutely controlled corticospinal activities the pyramidal tract is the outstanding voluntary motor pathway.

NONEEXISTENCE OF EMERGENT FIBERS IN THE DORSAL ROOTS OF THE SPINAL NERVES

Whether or not the dorsal or posterior roots of the spinal nerves, which carry afferent (sensory) fibers into the spinal cord, also contain emergent fibers is an old question, which has been answered in the affirmative by some, in the negative by others. Dr. W. H. L. Westbrook and Dr. Sarah S. Tower have re-investigated the problem, using a new method or sequence of experimental steps. In adult cats three dorsal root ganglia were removed under anesthesia, and time (4 weeks) was allowed for degeneration of all the nerve fibers proceeding from the ablated ganglia. Next, the proximal stumps were severed close to the cord and the dorsal roots, now isolated from the rest of the nervous system, were left in place for 2 weeks. If there had been originally any emergent fibers from the cord, these would have escaped degeneration after removal of the ganglia. They would, however, have degenerated after the proximal section and, in view of the time elapsing before autopsy, they would (if myelinated) have been in process of degeneration and would have been visible in the Marchi preparations. No such fibers were observed.

By use of the Bielschowsky technique much evidence was obtained that after ablation of the ganglia or section of the roots, there is prompt and vigorous growth of extraneous fibers into the vacated root. This finding no doubt explains the supposed emergent fibers seen by some previous workers. Careful search of the Bielschowsky preparations revealed during the critical 2 weeks after ganglionectomy no fibers which were not unmistakably either degenerating or regenerating. It is concluded that the concept that nerve fibers emerge from the spinal cord

into the posterior roots in adult mammals is without foundation.

FIBRILLATION IN DENERVATED MUSCLE

It has usually been thought that the atrophy of skeletal muscle which occurs after its nerve supply is cut is due to disuse. A contrary hypothesis suggests, however, that denervated skeletal muscle atrophies because it is fatigued by ceaseless fibrillary contractions. Dr. Sarah S. Tower has found by experimental observation that fibrillation caused by denervation

continues for months and even for more than a year, indeed as long as the denervated tissue is recognizable as muscle. The persistence of fibrillation is therefore such as to permit the hypothesis that it underlies the atrophy of denervated muscle.

Atrophy also follows severance of the tendinous attachments of muscle. Dr. Tower finds, however, no fibrillation in tenotomized muscle. She suggests that even in this case, spasmodic contraction going on to myostatic contracture may produce atrophy by exhausting the muscle.

THE CHROMOSOMES

CHROMOSOME REARRANGEMENT AND EVOLUTION

Dr. C. W. Metz, in a lecture given at the International Congress of Genetics at Edinburgh in September 1939 (but not yet published because of the interruption of the Congress by the outbreak of war), reviewed his recent work on chromosome rearrangement in the dipteran fly *Sciara*. The enormous size of the salivary-gland chromosomes in Diptera makes it possible to observe directly any changes which may occur in the chromosomes, whether spontaneous or induced, as indicated by the pattern of chromatic discs. Dr. Metz and his co-workers have found that in *Sciara* small localized alterations of pattern, such as deficiencies and duplications involving one to four discs, are very common, whereas translocations or inversions of large portions of chromosomes, which are frequent in *Drosophila*, are rare in *Sciara*. The same is true of hybrids between species of *Sciara*, bred in the laboratory.

Spontaneous inversions and translocations of parts of chromosomes have been called upon to explain the evolutionary differentiation of species; yet there are indications that the genus *Sciara*, in which large changes are rare, is at the present time undergoing marked evolutionary change. Dr. Metz supposes therefore that the small modifications of chromosomes characteristic of *Sciara* must also provide an adequate mechanism of evolutionary change in the germ plasm.

Experimental alteration of chromosomes, by irradiation of the male flies, is considerably less effective in *Sciara* than in *Drosophila*. Dr. Metz offers the conjecture that such differences in susceptibility to X-rays may depend upon some sort of protective sheath about the chromosome threads, which is more easily modified by the rays in one species than in another. If, for example, in *Sciara* the chromosome sheath is more resistant than in *Drosophila*, we might expect chromosome alterations to be restricted to minute localized changes such as could occur within the sheath.

THE MECHANISM OF INDUCED CHROMOSOME REARRANGEMENT

As previously reported, Metz and Boche found that in oöcytes of adult females of *Sciara* the chromosomes are very resistant to irradiation, as judged by the difficulty of inducing chromosome rearrangements. In sperm cells rearrangements were readily obtained. Since this result is quite different from that of similar work with *Drosophila*, it was thought that possibly the difference was due to difference in the mode of development of the oöcytes in the two genera. In *Sciara* the adult females contain only relatively old oöcytes, and these might be especially resistant to irradiation because their chromosomes are in a condensed state.

An extension of the study by Dr. Metz and Dr. Bozeman, however, leads to a different interpretation. The results indicate that in

Sciara the chromosomes are resistant to irradiation for a much longer period than was formerly supposed, even during the prophase, when they are long and threadlike. In other species the chromosomes in such a state are sensitive to irradiation. The only plausible explanation of the relative insensitivity of *Sciara* chromosomes seems to be that the broken ends of irradiated chromosomes fail to move enough to form new combinations. On cytological examination of irradiated eggs, Dr. Metz and Dr. Bozeman find no evidence of clumping or breakage of chromosomes, a fact which supports the hypothesis that the infrequency of rearrangements within chromosomes after irradiation is due to lack of chromosome movement.

ORGANIZATION OF THE GIANT CHROMOSOMES

In spite of their relatively great size, the giant salivary-gland chromosomes are still absolutely small enough to test the highest powers of the microscope, and several different interpretations of their structure have been put forward. Dr. Metz, in an article in the *American Naturalist*, gives reasons, backed by photographs, for thinking that the chromosomes consist of a series of transverse chromatic discs, seen in side view as crossbands, and that each pair of discs is separated by a single layer of nonstaining (achromatic) droplets embedded in the true chromosome substance, which extends longitudinally between the droplets from one disc to the next. Dr. Metz supplies diagrams explaining how other students of the subject may have arrived at erroneous interpretations by analyzing the same appearances in other ways.

SPONTANEOUS CHROMOSOME BREAKAGE

In a preliminary communication Dr. Metz reports that in *Sciara reynoldsi* one chromosome pair regularly breaks into two segments during development, in the salivary glands but not in ordinary embryonic cells. This

provides additional evidence that the salivary-gland chromosomes are highly modified structures. Here, as in the somewhat similar case described previously in *S. ocellaris*, the break probably occurs at the region of the centromere. It is postulated that two centromeres are present and that they separate to effect the break. The phenomenon may have a bearing on the mechanism of evolutionary change in chromosome number.

AN EVOLUTIONARY CHANGE IN CHROMOSOME SHAPE

In the fly *Sciara ocellaris* two types of chromosomal pattern are found. In the "bisexual" strains (in which single females give both male and female offspring) there are 4 V-shaped chromosomes and 4 rods. In the "unisexual" strains (in which a single female gives only male or female offspring) there are 2 V's and 6 rods. In the closely related species *S. reynoldsi* there are always 4 V's and 4 rods; all the known strains are "bisexual." In both species the two pairs of V's are autosomes, the sex-chromosome pair being rod-shaped.

By crossing the "bisexual" and "unisexual" strains of *S. ocellaris*, Dr. Helen V. Crouse obtained an F₁ generation showing 3 V-shaped chromosomes and 5 rods. The odd V and one of the rods appear to be of the same length, and it was supposed that the V chromosome had originated from a rod by the occurrence of a large transposition. The large chromosomes of the salivary glands, however, show no such transposition, and Dr. Crouse now supposes that this change in the form of the chromosome was produced by translocation of the point of attachment of the spindle fiber. The genetic significance of the heteromorphic chromosome pair and its relation to the determination of "bisexuality" and "unisexuality" in *S. ocellaris* remain to be investigated.

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DEPARTMENT OF GENETICS

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The Department of Genetics is interested not alone in the detailed mechanisms of heredity—how chromosomes with the genes which they carry are distributed at the division of cells in reproduction and growth, and how chromosomes and genes are changed under various types of stimulation. It is interested in the broader problems of evolution, and attempts to relate its laboratory findings to the processes which have brought about the diversity in nature as we see it today. It is specifically interested in growth and development and the directive forces inherent in the assemblage of genes possessed by the living plant and animal. It is interested in the action of hormones, which in many forms are the medium through which control of development is exercised. It is equally interested in cases in which the mechanisms for orderly development break down and uncontrolled growth results. Through these different interests and different points of view a clearer picture is unfolding of how the living organism becomes what it is.

Detailed reports of the work of the different research groups for the past year, ending September 1, are given in the following pages. The chief results of these investigations may be briefly summarized.

The group which has been concerned primarily with the gene has contributed further evidence on the nature of genes by means of induced mutations. Drs. Demerec and Sutton have found evidence which indicates that there is a sensitive region on each side of a gene. If the chromosome is broken within this sensitive region and the broken segment attached to some unrelated section, the gene is frequently affected. The length of the sensitive region varies with the locus and is also influenced by the nature of the recipient section. Dr. Kaufmann's studies indicate that broken chromosome segments induced by X-rays in the sperm of *Drosophila* do not

rejoin for at least 16 days after the treatment, probably not until the sperm enters the egg. Drs. Demerec and Hollaender found that monochromatic radiation of 2280, 2650, and 2950 Å produces lethal mutations in the sperm of *Drosophila*. Drs. Demerec, Kaufmann, and Sutton, in collaboration with Dr. Tuve, of the Department of Terrestrial Magnetism, have found that changes in chromosomes of *Drosophila* induced by neutrons are similar to changes induced by X-rays.

The group which has been interested especially in the grosser structure of chromosomes has continued to explore the numerous problems in development and heredity which the new method of inducing chromosome doubling has opened up. By means of induced pericinal chimeras with different chromosome numbers, Miss Satina has definitely established the presence of three germ layers in *Datura* and determined the contribution which these layers make to the different plant organs. Dr. Sinnott has analyzed the influence of chromosome number upon the number, size, and shape of cells and also upon the relative frequencies of division in different planes which are responsible for differences in size and shape of fruits in cucurbits. Drs. van Overbeek and Conklin have studied the effect of various stimuli on the reproductive processes in plants and conclude that there are different steps in the production of fertile seed which require different stimuli for their initiation. Auxin is necessary for retaining the ovaries. The stimulus for later development of egg cells, which, if discovered, might be used to induce parthenogenesis, is believed to be proteinaceous in nature. Cooperative studies with Dr. W. J. Robbins on the physiological differences between $1n$, $2n$, $3n$, and $4n$ *Daturas* have been started and sterile cultures of excised roots of these chromosomal types have been secured for experimentation. By means of

induced tetraploids in the dioecious plant *Melandrium dioicum*, Dr. Warmke has shown that the X chromosome carries factors for femaleness, the Y carries even stronger factors for maleness, and the autosomes have no significance in sex expression. By changing the balance between the numbers of X and Y chromosomes, hermaphrodites have been secured, and a method has been devised for purifying this dioecious species through selfing such hermaphrodites. By finding chromosomal bridges, Dr. Bergner has evidence that inversions are not infrequent in races of *Datura*. She has evidence of position effect from results of a spontaneous somatic interchange. Miss Satina is now able to identify all the chromosomes in *Datura* as well as to distinguish their individual ends by study of structural differences. Mr. Avery has summarized the known genes in *Datura*. Seventy-two have been located in particular chromosomes. Over 380 genic types have been recognized the genes for which have not yet been located.

The group working on genetic aspects of development in mice have completed the experimental part of an extensive study upon the mechanism responsible for the inheritance of the tendency to produce spontaneous leukemia. The results of previous hybridization studies, which include only the first hybrid generation and a first backcross, could be interpreted equally well by the action of genes or of nonsegregating materials. The reduced incidence of leukemia in the backcross did not indicate whether the segregation of genes was giving these animals diverse leukemic potencies or whether each mouse "inherited" the same dilute leukemic potency, which was expressed less frequently because weaker. The only possible approach to such a question was to make a breeding test of each backcross animal. This experiment has now been repeated, with the addition of breeding tests of 50 backcross animals, from each of which over 50 young have been bred, making a total of over 2800 offspring in a second backcross generation that have been raised, held until death, and autopsied. The conclusions are given in terms of the incidence of leukemia

in each of the second backcross families: instead of classifying the backcross animals into two groups, leukemic and nonleukemic, each backcross animal is classified according to the performance of its offspring. This appears to be the first time that such an analysis of a segregating generation has been attempted in the genetic study of any spontaneously occurring malignant growth. Although the histological diagnoses are incomplete, a preliminary survey of the data indicates with certainty that an interpretation calling for one outstanding gene pair is eliminated.

The group interested in endocrine glands has concentrated its work on the action of the hormones of the pituitary. Through use of large numbers of pigeons whose pituitary glands had been removed, two pituitary hormones—prolactin and thyrotropin—have been shown to have special action on the growth and maintenance of the pancreas in these animals. Though these and all other pituitary hormones are unable to exert this action in completely fasting birds, either prolactin or thyrotropin is partly effective and a combination of these two hormones produces abnormally large pancreases in normal birds and in those whose pituitaries have previously been removed. These hormones exercise this action partly by increasing appetite and food consumption, but force-feeding alone without hormone injection only partially sustains the pancreas. It is not yet known whether or to what extent these hormones have a similar action on the pancreas of other animals and man. Still another action of prolactin is found to be much increased or potentiated by some other product or products of the pituitary gland. When purified prolactin is injected into pituitaryless pigeons for as much as 10 days it increases the weight of their crop sacs much less than when the same amount of prolactin is administered in impure (unseparated) form (Drs. Schooley, Riddle, and Bates). These instances extend the known range of processes regulated by the pituitary gland and provide further instances of interrelationship and synergism among the pituitary hormones. A useful method was developed for assaying

pituitary extracts and preparations for their ability (adrenotropin) to stimulate the adrenal glands. Two-day-old chicks are injected daily for 5 days and any enlargement of their adrenals is then determined by weighing. Several other pituitary and nonpituitary substances have been shown to have no effect upon this reaction on cortical tissue in the chick, and the method has the additional advantage of permitting a simultaneous assay of thyrotropin and gonadotropin in the preparations thus examined. Largely in consequence of advantages possessed by this method of assay, it has also been possible to devise a method of preparing highly potent adrenotropic fractions essentially free from prolactin, thyrotropin, and gonadotropin (the relationship of LH, or luteinizing hormone, to adrenotropin is uncertain) (Drs. Bates, Riddle, and Miller). An unusual result was obtained from a combination of two agencies which separately reduce the metabolic rate. It is well known that both fasting and hypophysectomy cause a very marked decrease in rate of heat production in various animals, including pigeons. It is now established that when immature (2-month) pigeons are fasted for 10 days following removal of their anterior pituitary glands, the decrease in their rate of heat production, measured at either 25° or 30° C., is less than that in their unoperated mates. This result may therefore be described approximately by the expression "one plus one equals one-half" (Dr. Riddle and Mrs. Smith).

Dr. Steggerda, who heads a group on anthropology, has spent a large part of the

past year on his manuscript on studies in Yucatán, but has also carried on field work on racial differences. He finds that the growth pattern for Zuñi children is practically the same as that previously demonstrated for Navajo, Maya, Negro, and Dutch white children. All these children grow rapidly at about 6 years of age, then decrease in their rate of growth until 9 or 10 years, and then have another spurt of growth which lasts until about 14 years, when the rate of growth begins to fall off rapidly. The order in which the permanent teeth appear in the mouth is the same for all the races considered. In general the lower teeth erupt earlier than the upper ones. Tooth eruption is somewhat earlier in females than in males. Dr. Steggerda has discovered an instrument in use for getting sections of wool fibers with which he has been able to cut 150 cross sections of individual human hairs at one time, instead of only one, as was the case with the usual microtome method. It has thus become possible to analyze statistically hair size and shape, which Steggerda finds vary greatly in the same individual. He has found statistically significant differences among the American Indians, Negroes, and Dutch whites in respect to hair characters. Steggerda has tested the value of different anthropometric measurements as criteria for distinguishing identical twins, which are the products of a single egg, from fraternal twins, which come from two different eggs. Vertex height, weight, and certain other measurements were found to be statistically more reliable than many that have been used.

CHROMOSOME INVESTIGATIONS

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M. E. Conklin, E. W. Sinnott, and J. van Overbeek*

In our last two annual reports we have described methods of inducing the doubling of chromosome number by use of the alkaloid colchicine and have given preliminary results of studies on the effects of induced polyploidy. Colchicine is not the only chemical which will induce doubling of chromosome number, al-

though it appears to be the best so far known for this purpose. Phenyl urethane, first used by Lefèvre to induce polyploidy, we have found to be potent, but effective with *Datura* only within a narrow range of concentrations. Thus, when seeds were soaked in a saturated solution (about 0.01 per cent) for 2 days,

75 per cent of those which lived appeared to be tetraploid. However, seeds soaked in 0.009 per cent solution for 4 days gave no tetraploids.

PERICLINAL CHIMERAS

New tools often make possible new insights into life processes. The method of doubling chromosome number at will is proving to be a tool of greater value than was at first realized in throwing light on problems of development and evolution. A striking example is the formation of periclinal chimeras, which frequently result from colchicine treatment when only some of the germ layers are affected by the drug. Further studies made by Miss Satina of 68 periclinal chimeras have definitely demonstrated the presence of three independent germ layers in the primordia of *Datura*. The cells of the central core, which have been generally believed to constitute a tissue of independent origin, she has shown to be derived entirely from the third germ layer. Various combinations of $2n$, $4n$, and $8n$ layers have given nine types of periclinal chimera in which one, two, or three germ layers were polyploid. The most frequent changes in chromosome number occurred in the outermost germ layer, the least frequent in the second layer. At very early stages of development the three germ layers differ in the contribution which they make to the primordia of different organs. Thus, most of the inner tissue of leaves, petals, and sepals is formed by the second layer, while the inner cells of the stamens and of the pistil consist chiefly of cells which have originated from the third or innermost layer. The theory current in textbooks is that pistils and stamens are phylogenetically closely related to leaves. If the ontogenetic development in the different organs can be properly used as an index to phylogenetic relationships, our findings seem to indicate that sepals and petals are closely related to leaves but that the relation of pistils and stamens to leaves is more remote.

The loose inner tissue of the style through which the pollen tubes grow appears to be formed chiefly, if not entirely, from the outer-

most or first germ layer, which gives rise to epidermis of stems and leaves. The periclinal chimeras appear to show that it is this loose inner tissue of a $2n$ style which causes the $2n$ pollen tubes from a $4n$ plant to burst before reaching the ovary, since the style of a periclinal chimera with a $2n$ epidermis but otherwise $4n$ causes $2n$ pollen tubes to burst in the same way as does a style of a plant which is $2n$ throughout.

This past season more than 100 plants from colchicine-treated seeds were recorded for polyploidy from appearance and tested for periclinal chimeras by histological study. If only a single germ layer had its chromosomes doubled, the greatest visible effect was produced when the innermost layer was tetraploid, and the least effect when the epidermis was tetraploid. Thus the ability to produce periclinal chimeras through the use of colchicine has enabled us to label the different germ layers and to determine the contribution which each makes to the development of the various organs of the plant.

POLYPLOIDY IN CUCURBITS

One of our profitable cooperative investigations is the study of the effects of polyploidy upon the developmental processes in cucurbits which is being carried on by Dr. Sinnott with the assistance of Mrs. Alicelia Franklin.

The investigations on the relation of chromosome number to fruit size and shape in cucurbits have been considerably extended, and data are now available on twelve pure lines in the genera *Cucurbita* and *Lagenaria*. In every case there is observable the tendency for the tetraploid race to have wider and shorter fruits than the diploid race from which it was derived. This is evident not only in the fruits, but also in the leaves. The dimension at right angles to the longitudinal axis of the organ is increased much more than the others, evidently by more extensive cell division in this direction. The final size of the organ is approximately the same in tetraploids as in diploids, no sign of gigantism being seen except in one line. Since the cells are twice as large in tetraploids as in diploids, this

means that the former have only about half as many cells per organ. Evidently increasing the chromosome number decreases the number of cell divisions, although it increases the size of the cells.

Developmental studies on fruits of these various lines have been continued and considerably extended. The lines all agree in showing that the tetraploids are larger-celled from the beginning and that this advantage is maintained until the end of development. The problem of the relation between the cellular differences and the differences in fruit shape between tetraploids and diploids is being examined.

ATTEMPTS TO INDUCE PARTHENOGENESIS

The success of efforts to find a method of inducing an increase in the number of chromosomes has led to search for methods by which to reverse the process. The counterpart of the colchicine method, by which the chromosomes in the cells of plants are doubled in number, would be a method which would reduce the number of chromosomes by half. If this could be done experimentally it would be of considerable practical and theoretical significance. By the combination of such a method with colchicine treatment, a quick way would be made available to establish pure lines of plants. The method used by itself would enable one to obtain simpler forms from naturally occurring multiple diploids, which would mean that the wheels of evolution could be turned back. With this in mind, it was deemed profitable to study the problem of induced parthenogenesis, which appears the most logical method to obtain plants with reduced chromosome number. With numerous growth hormones available, either in crystalline form or as highly concentrated extracts, it seemed worth while to test their possible utility for the induction of parthenogenesis. The problem has been studied during the summer of 1940 by Drs. van Overbeek and Conklin.

Some form of auxin was found to be indispensable for retaining the developing ovaries on the plants, and, of the different

kinds tested, naphthalene acetic acid proved to be the best. Not only does auxin induce development of the carpels, as was earlier found by Gustafson and reported by us last year for *Datura*, but if injected into the ovaries it also caused a considerable enlargement of the ovules. When applied as an emulsion on the outside of the ovary or just below the flower on the peduncle, it caused development of the carpels alone, with hardly any development of the placenta and ovules.

In addition to the growth of the carpels and enlargement of the ovules, a pseudo-embryo in $4n$ *Datura* was formed under the influence of naphthalene acetic acid. This pseudo-embryo, which is a novel discovery, appears to be formed by proliferation of the inner layer of the integument, sometimes called the endothelium. It consists of several hundred compact cells rich in protoplasm. In an early stage of development it fills the space normally taken by the embryo sac. The pseudo-embryo is surrounded by cells which degenerate, perhaps under the influence of the developing pseudo-embryo. About 14 days after treatment the pseudo-embryo, like the normal embryo, is found lying in the embryo sac, surrounded by degenerating integumental cells. The chief difference in appearance lies in the fact that the normal embryo sac is filled with endosperm tissue, whereas the embryo sac of the treated plant does not contain anything but the pseudo-embryo.

Attempts to stimulate ovules beyond the stage induced by auxin through additional injections of traumatic acid, biotin, pantothenic acid, many vitamins and other physiologically active substances, yeast, and pollen extracts have failed so far.

A study of the literature in combination with our own experiments indicates that at least two different substances are involved in the production of parthenogenetic embryos, each one initiating a definite step in the development of the embryo and the seed and fruit in which it is contained. One of the substances responsible for the first step is either auxin or a substance leading to its release in the ovary. This step is completely

under experimental control. Indications are that the other substance has a limited area of activity and may be proteinaceous in nature. If this substance could be identified or extracted and introduced into the embryo sac, the problem of artificial parthenogenesis might be solved. Though we have not yet solved this problem, we have learned something about the stimuli required for the various processes involved in setting of fruits and in the development of seeds.

POLYPLOIDY IN EXCISED ROOTS

Since doubling of chromosome number is an established method of evolution of plants in nature, it seems desirable to learn what we can of the physiological as well as the morphological responses to increased amounts of chromosomal material. We are fortunate in having secured the cooperation of Dr. W. J. Robbins in an attack upon the physiological phases of the problem through the use of excised roots of $1n$, $2n$, $3n$, and $4n$ Daturas. These can be grown in sterile cultures on synthetic nutrient media under more closely comparable conditions than would be possible when dealing with entire plants. Some difficulty was at first encountered in getting sterile roots from cuttings of these four balanced chromosomal types. Now that this problem appears in the way of being solved, it should soon be possible to determine what differences exist among these types in physiological reactions. Dr. Robbins reports that he has induced an excised root of a $2n$ *Datura* to grow 5 cm. in less than 24 hours. This is probably the record so far for speed of growth of an excised root.

POLYPLOIDY AND THE SEX MECHANISM IN MELANDRIUM

Most flowering plants are hermaphroditic, having both pistils and stamens. A few, such as the poplars and willows, are dioecious and, like the higher animals, have the sexes separate. There is evidence that doubling of chromosome number has been of evolutionary significance among dioecious as well as among the more common hermaphroditic species of

plants. The dioecious species *Melandrium dioicum* is insect- rather than wind-pollinated, has sex chromosomes which can be readily distinguished, and in other ways is especially adapted to genetic study. For these reasons it has been chosen for an intensive study which has been carried on by Dr. Warmke. It is now possible to add considerable to our preliminary report of last year.

The role of the X chromosome and autosomes in sex determination in *Melandrium* is now definitely established. The X is female-determining, as shown by the following series:

Chromosome constitution	X/Y ratio	Sex
4A + XY	1.0	Male
4A + XXY	2.0	Male (rare ♀ blossom)
4A + XXXY	3.0	Male (occasional ♀ blossom)
4A + XXXXY	4.0	Hermaphroditic (occasional ♂ blossom)

The autosomes in *Melandrium* are unimportant in sex determination. In the following series the ratio of X chromosomes to autosomes is changed by a factor of 3, but sex is not altered.

Chromosome constitution	X/A ratio	Sex
2A + XXX	1.5	Female
4A + XXXXX	1.25	Female
2A + XX		
3A + XXX	1.0	Female
4A + XXXX		
4A + XXX	0.75	Female
3A + XX	0.66	Female
4A + XX	0.5	Female

Thus sex is determined in *Melandrium* by a balance between X and Y chromosomes, and not between X chromosomes and sets of autosomes, as in *Drosophila*.

It is evident that hermaphroditic plants are at an advantage over dioecious animals and plants in that they can be quickly rendered homozygous through selfing for a few generations. In an attempt to free our dioecious *Melandrium* material from possible

heterozygosity, a relatively rapid method of purifying the stocks through selfing was devised. By adding an extra chromosome to diploid plants, individuals with the constitution $2A+XXY$ have been obtained. These plants are predominantly male, but produce a few self-fertile hermaphroditic blossoms. Among the offspring of such flowers are normal $2n$ males and females and more plants of the type $2A+XXY$. These latter may again be selfed, and the process continued as long as segregation occurs. When the stock is sufficiently pure, the extra chromosome may be eliminated, leaving a relatively homozygous stock, consisting of normal $2A+XY$ males and $2A+XX$ females. The long and laborious task of purifying a dioecious stock through brother-and-sister matings is thus avoided.

A sexually reproducing race deficient for two sex chromosomes has been produced in *Melandrium*. By selecting and intercrossing $4n$ plants which had lost one sex chromosome through non-disjunction, plants deficient for two sex chromosomes have been obtained. Such plants, $4A+XX$ (female) and $4A+XY$ (male), are tetraploid for autosomes but diploid for sex chromosomes. These plants are viable and fertile; it was expected that by crossing them, a true-breeding race consisting of approximately equal numbers of males and females similar to the parents would be obtained. Incomplete field records bear out this expectation but reveal a considerable excess of male plants. It is possible these findings may offer an explanation for the polyploid species in willows, for example, in which the autosomes appear to be doubled but in which only a single pair of sex chromosomes is evident.

CHROMOSOME INVERSIONS

A major problem of our group has had to do with the chromosomal changes which occur in nature. Earlier reports on segmental interchange in *Datura stramonium* have been based on study of 680 races. It is now possible to report on a preliminary survey by Dr. Bergner of hybrids between our standard

Line 1 of this species and 36 other races in respect to evidence for inverted segments in the chromosomes. When crossing over takes place in a plant heterozygous for an inverted segment distal to the centromere, a chromatid bridge and a fragment may result. Chromatid bridges were found occasionally in most of these *intra se* hybrids, those found at T I, M II, A II, and T II being considered as reliable evidence of inversions, but their frequency probably would not be above 2 per cent as a maximum. The bridge usually was heavy, but not always. The fragment could be found only very rarely, and when it was seen it usually was quite small and lay close to the bridge. These observations led to the conclusion that inversions which do not include the centromere are present in many races of *Datura stramonium* but that they are short regions and lie close to the ends of the chromosomes.

In three species hybrids, at least two different chromosomes gave evidence of inversions. Other than the relatively greater frequency of chromatid bridges, the only peculiarity which seems to distinguish the *inter se* from the *intra se* hybrids is the lagging of chromosomes, which is quite noticeable in five of the former.

CHROMOSOME INTERCHANGE GIVES EVIDENCE FOR POSITION EFFECT

This past season a bud sport was found on one of our *Datura* plants which has proved of considerable interest. The plant was heterozygous for what we have been calling a dominant gene, Rough-4 (Rf-4), which renders the leaves rough. The gene is apparently located in the .1 half-chromosome of Prime Type 51, in which this .1 fragment had been translocated to the 11.12 chromosome by means of the satellite on the .12 end. Dr. Bergner found that in a bud sport which differed from the parent plant in having smooth leaves and more vigorous growth, a segmental interchange had occurred such that the .1 half-chromosome was transferred to the 21.22 chromosome. The fact that when the .1 fragment was attached to another chromosome the leaves were normal in ap-

pearance indicates that the roughness when the fragment is attached to the 11·12 chromosome must be considered due to a position effect. This interpretation is confirmed by the character of the offspring in the next generation. The interchange is also of interest since it is the first demonstrated chromosomal change of this kind in *Datura* which has taken place spontaneously in somatic tissue.

VISIBLE DIFFERENCES BETWEEN DATURA CHROMOSOMES

For some time Miss Satina has been investigating the differences in size and structural differentiation of the chromosomes in *Datura stramonium*. By study of the chromosomes of prime types and of $2n+1$ types in pollen grains and root tips, she has found that each of the 12 different chromosomes is divided by the insertion region into two arms of unequal size. The longest primary chromosome (1·2) averages 4.0 microns, the shortest (23·24) averages 1.8 microns. The longest secondary chromosome (1·1) averages 4.5 microns, the shortest (19·19) averages 1.8 microns. Seven of the 12 chromosomes have satellites on one of the arms (the 3·4, 7·8, 9·10, 11·12, 19·20, 21·22, and 23·24 chromosomes). Only one of the chromosomes, $2n+10\cdot10$, has as its extra chromosome a satellite arm doubled. Each chromosome has thus a visible individuality, and Miss Satina is now able to distinguish each from all the others and to identify the individual ends.

GENES IN DATURA

During the progress of the *Datura* work there have been gradually accumulated new tools in the way of methods and plant testers which have made possible more effective attacks on the problems of heredity and evolution.

An ample collection of genes with which to tag the various chromosomes and parts of chromosomes is considered an important element in the geneticist's chest of tools; and one of the questions most frequently asked regarding an organism used for genetic investigation is, How many genes has it available for

study? Since a general report on the collection of genes in *Datura* has not before been made, Mr. Avery has prepared the accompanying tables, which list the more distinct characters which up to the end of the present summer have been discovered and classified as due to genes. They have come from races in nature, from rare spontaneous mutations in our cultures, from hybrids with other species, from aged seed, and from treatment with heat, radium, radium emanation, and X-rays. A total of 72 have so far been located in particular chromosomes and 29 of these have been placed in a particular half-chromosome. A considerable number have had their relative positions in the chromosome determined by linkages. Of the more than 380 other genes, many are in process of being located. Genes have been located in all the 12 chromosomes, the smallest number being 3, in the 7·8 chromosome, and the largest number 9, in the 11·12 chromosome. As will be seen from the last column of the general table, the genes for the various groups of characters are well distributed among the different chromosomes. The genes differ greatly in their value as labels by which to follow chromosome behavior. Those like the genes for white are especially valuable since they do not adversely affect the growth of the plant and are recognizable in the early seedling stage.

Of particular interest are the pollen-abortion genes, which cause the abortion of the pollen grains in which the gene is present without affecting the viability of the egg cells. These pollen-abortion genes therefore are of exceptional value in determining the position of genes within a given chromosome in which they have been located by other methods. For example, a plant heterozygous for pa-5, which is in the 17·18 chromosome, was female crossed to curled-1 (c-1), the gene for which is in the same chromosome. In the F₁ all the plants were heterozygous for c and those with 50 per cent aborted pollen were also heterozygous for pa-5. One of the latter was male backcrossed to curled. Since none of the chromosomes containing pa-5 could function in the male, all the offspring from this male backcross were curled except 24 per

CHARACTERS AND GENES IN *DATURA STRAMONIUM*

Character	No. recognized	No. located in particular chromosome	No. different chromosomes
albino.....	48	4	3
pale.....	52	9	6
sickly and spotted leaves.....	27	4	3
rough and glaucous leaves.....	12	3	3
Bronze.....	1	1	1
other leaf characters.....	39	4	4
wilt.....	11	3	3
white flowers.....	4	3	3
nonflowering.....	1	1	1
early fruiting.....	2	1	1
capsule characters.....	6	4	4
red seed.....	1	1	1
curled cotyledons.....	5	2	2
other seedling characters.....	8	..	..
compact.....	10	3	3
other habit types.....	62	7	4
male sterile and female fertile.....	5	1	1
male sterile and female sterile.....	5	..	..
pollen abortion.....	105	11	8
other pollen types.....	14	4	4
pollen-tube types.....	42	6	5
Totals.....	460	72	

LOCATION OF 72 GENES IN *DATURA STRAMONIUM*

Chromosome	No. genes located in chromosome	Names of genes
1·2.....	5	albino-11; pale-7*; pale-16*; spotted-leaves*, Rough-4*
3·4.....	8	Bronze†; ferox white†; tufted†; Q-spot; glaucous-1; albino-10; albino-12; nonflowering
5·6.....	6	sickly-3; pale-19; mottled; pa-2; pa-12; slow-pollen-tube-2
7·8.....	3	pale-25; fused; puckered
9·10.....	4	red seed; dyad; Male sterile-1; pa-24
11·12.....	9	inermis†; earlyt; pa-22*; triforked; sickly-1†; wilt-3; short flowers†; lobed-pollen†; chromosome doubling†
13·14.....	7	albino-2*; pa-8; pa-11; peach; wilt-4; short-pollen-tube-2; pre-germination pollen
15·16.....	8	pale-5†; pale-8*; glaucous-3*; tricarpel†; rough-3; white-2†; compact†; short burst pollen tube-3
17·18.....	6	curled-1*; white-1†; wilt-1*; pa-5†; pale-6; short burst pollen tube-2†
19·20.....	5	short*; curled-2†; short pollen tube-1; pa-1*; pa-16*
21·22.....	6	pale-1; pale-3; slender capsule; asynapsis; bunchy-2; pa-17
23·24.....	5	swollen; broad leaves-1; zigzag; ragged leaves; pa-23

* Located in odd-numbered chromosome half.

† Located in even-numbered chromosome half.

cent which were crossovers. By the use of pa-5 it was possible to show that the locus for white-1 is 4 units from that of pa-5; c-1 is 24 units distant; wt-1 is 26 units, and pl-6 is 29 units. The use of pollen-abortion testers in locating genes within chromosomes avoids the loss of time involved in making up a double recessive, necessary for the current linkage method, and also avoids the breeding difficulties inherent in handling double recessives, which tend to be lacking in vigor. As will be seen from the table, at least one pollen-abortion gene has been located in 8 of the 12 chromosomes. It should not be long before such genes will have been located in the 4 remaining chromosomes. *Datura* is the only form in which pollen-abortion genes have been utilized for location of genes, but they will doubtless be used with other forms when their value is realized. So far as the number of genes which have been located within particular chromosomes is concerned, *Datura* is better equipped with tools than any other plant with the exception of maize.

CHROMOSOMAL TYPES IN DATURA

In respect to chromosomal types for use as testers, *Datura* is even better equipped than in respect to recognized genes. Over 200 types have been identified which have chromosome numbers differing from normal. Among these are all the 12 possible primary $2n+1$ types, in which the extra is an unmodified chromosome; 14 of the theoretically possible 24 secondary $2n+1$ types, in which the extra is a double half-chromosome; and a considerable number of tertiaries, in which the extra has ends from two different chromosomes. Trisomic ratios from $2n+1$ types were first used in *Datura* for the location of genes in particular chromosomes and have provided the preferred method for this purpose also in maize. No plant is better supplied with $2n+1$ types than *Datura*.

Compensating types lack one normal chromosome, which is compensated for by the presence of two modified chromosomes which together supply the missing chromosomal material and bring in extra material which

affects the appearance of the plant. Compensating types are of considerable value in purifying heterozygous material and in locating genes in particular chromosomes in ways which have been described in earlier reports. No compensating types have been developed as yet in other plants than *Datura*, in which there is at least one to use as a tester for each of the 12 chromosomes.

In *Datura stramonium* there are tested plants of the balanced series $1n$, $2n$, $3n$, and $4n$. In 10 species, which comprise all the known herbaceous species of *Datura* in nature, there are tetraploid races which have been induced by means of colchicine treatment.

In *Datura stramonium* there is a collection of over 90 different purified prime types, which are races with chromosomes some of which are modified, chiefly through segmental interchange. Prime types are useful for linkage studies and as a source of tertiary chromosomes which may be used in making up compensating types and in synthesizing new species.

There are 10 pure-breeding artificial new species in *Datura stramonium*, which have been synthesized with extra chromosomal material.

There is under cultivation a collection of over 1100 races of the herbaceous species of *Datura* from widely separated places throughout the world, which have been tested for certain chromosomal differences and which are kept available for further evolutionary studies.

As reported earlier, chromosomal types due to segmental interchange have been discovered in tests of nearly 700 races from nature in *D. stramonium* and also in most of the other species of *Datura*. These types are kept in our collection of living reagents for tests of the mechanisms of evolution. To this end all the herbaceous Daturas except one have so far been tied up directly or indirectly by means of hybridization with *D. stramonium* in order to interpret the evolution of chromosomes within the genus in terms of the chromosomes of the standard line 1 of *stramonium*. Hybridization is diffi-

cult in most cases, and incompatibilities develop in later generations. However, extracted races from hybrids between *D. stramonium* and several of the other species have been established. Tester *stramonium* chromosomes have been gotten into extracted races which are otherwise *D. Leichhardtii* in order to use them as chromosomal testers with other species with which *D. Leichhardtii* will hybridize but which will not combine directly with *D. stramonium*.

With its chromosomal testers and with the collection of genes previously discussed, *Datura* has become at least one of the best-

equipped plants with which to study the problems of heredity and evolution. The progress that has been made in the *Datura* investigations has been due in part, we believe, to the centralization and close interrelation of the various aspects of the problem, but also to the generous support of the Carnegie Institution throughout the continuation of the work, and in recent years to the added support of the Carnegie Corporation. These factors together have made possible the cooperation of a number of investigators with different points of view and rendered the work a truly joint undertaking.

THE GENE

M. Demerec, B. P. Kaufmann, Eileen Sutton, and O. T. Hinton

In our studies on the nature of genes and chromosomes, extensive use was made of X-rays, neutrons, ultraviolet rays, and infrared rays. The work was carried on in co-operation with members of the staffs of the National Institute of Health, Bethesda, Maryland, the Department of Terrestrial Magnetism, Washington, D. C., and the Memorial Hospital of New York.

REACTION OF GENES TO CHROMOSOME BREAKS IN THEIR PROXIMITY

Among the changes induced by X-ray treatment in the tip region of the X chromosome of *Drosophila melanogaster*, we have 84 cases in which the genetic change was associated with a break in the chromosome. Cytogenetic studies carried on by Dr. Demerec and Dr. Sutton indicate that a sensitive region exists on each side of the locus; the gene is frequently affected if the chromosome is broken within this region and the broken segment attached to some unrelated section. The effect is probably produced by the change in position and may be due either to a change in the gene or to a change in gene activity. It was found that the length of the sensitive region is different for different loci and that it depends also on the nature of the recipient section. For rearrangements involving euchromatin, the length of the sensitive region as measured on Bridges' salivary-chromosome

map is at least 1 micron for the Notch locus, 2 for yellow and scute, and 3 for white and diminutive. As a rule transfers to heterochromatin increase the length of the sensitive region as much as five to ten times.

However, a gene is not affected by every break occurring within its sensitive region. Breaks closer to a locus are usually more effective than breaks farther from a locus.

GENETIC BEHAVIOR OF EUCHROMATIC SEGMENTS INSERTED INTO HETEROCHROMATIN

In the report of last year (Year Book No. 38, pp. 189-190) a description was given of the changes observed in a segment of the X chromosome, in the white-Notch region, which was inserted in the heterochromatin. During the past year genetic analysis of four similar insertions has been completed by Dr. Demerec. The first is N264-85, in which a large segment of 145 bands, from 3C1 to 6A1.2 inclusive, is inserted in the heterochromatin of the fourth chromosome. The genes white, roughest, facet, and diminutive, located in the left end of the segment, and the genes rugose, curlex, crossveinless, roughhex, and vesiculated, located in the right end, show mottling; the genes bifid, pebbled, and ruby, located in the middle, are not affected.

The second is ct268-37, in which a section

of 75 bands, from 5D₃.4 to 7B₁.2 inclusive, is inserted in inverted order into the heterochromatin of 3L. The loci roughex and vesiculated on one end of the segment show mottling, and the loci shifted and carmine on the other end are not affected.

The last two insertions, N264-86 and 264-100, are short. The first has a segment of 17 bands, from 3C₇ to 3E₅, inserted into the heterochromatin of the fourth chromosome, and the second has a segment of 45 bands, from 3C₁ to 4B₃.4, inserted into the heterochromatin of the third chromosome. All loci included in translocated segments show mottling.

The results of these experiments give a good illustration of the extent to which the loci brought into proximity with heterochromatin are affected. If a small segment is inserted into a heterochromatic region, all loci are affected, but if the segment is long, either the loci on both ends of the segments show mottling or only those loci which lie close to the chromocenter.

REVERSION OF ROUGHEST

Roughest³ of *D. melanogaster*, phenotypically expressed by irregularities in the eye facets, is associated with a long inversion in the X chromosome, extending from 3C₃ to the proximal heterochromatic region. Reversion of roughest³ to wild-type may be induced by X-radiation; see preliminary report in Year Book No. 38. Among 21,104 F₁ daughters of irradiated roughest³ fathers, Dr. Kaufmann and Mr. Hinton found 171 which appeared to be wild-type. Seventy-two were selected at random for analysis. Twenty-five of these produced no offspring; 7 others had low viability and were lost or discarded; 23 simulated wild-type owing to the variability of expression of roughest³; the remaining 17 were true reversions. Salivary-chromosome analysis of these 17 showed three general types of rearrangement, all involving breaks in the proximal heterochromatin of the X. Most frequently the roughest locus (3C₄) was transferred to a euchromatic region by inversion or translocation. In two

rearrangements the nucleolus-organizing region had been removed from the X chromosome, so that the roughest locus was brought closer to the centromere. Another type of change involved transfer of the X chromosome, including the roughest locus and the adjoining nucleolus-organizing region, from its own centromere to the euchromatic portion of an autosome. Since reversion accompanies such changes, it seems that the expression of roughest³ depends on the propinquity of the 3C₄ locus to that portion of the heterochromatin of the X which includes the nucleolus-organizing region, when this material occupies a position close to the centromere.

DOMINANT LETHALS

An experiment was undertaken by Dr. U. Fano and Dr. Demerec to determine the rate of production of dominant lethals in sperms of *D. melanogaster* by different doses of X-rays. The following points were tested:

1. Whether the rate of production of dominant lethals by a small dose of X-rays is significantly higher than the known rate of production of chromosomal aberrations, as is indicated by results of Bauer, Demerec, and Kaufmann. Comparable rates of production of dominant lethals and of cytologically detectable chromosomal aberrations would indicate that dominant lethals should be attributed mainly to aberrations of already known types, which are not viable because they contain acentric or both acentric and dicentric fragments. A higher rate of dominant lethals should, on the contrary, be attributed to some other kind of mutation process. Nongenetical (physiological) actions on sperms are not supposed to be very important, since the sperms consist mainly of genetic material.

2. Whether the rate of production of dominant lethals at small doses (250-1000 r) is proportional to the dose itself. Proportionality would possibly indicate that a single-break process—perhaps the production of large terminal deficiencies—is responsible for a great many of the dominant lethals.

3. Whether the residual fertility after high-dose irradiation (5000 to 10,000 r) depends

on the dose according to a theoretical expectation based on the probability that the genetic material of a sperm is not hit by the radiation.

Experiments involving counts of about 40,000 eggs are already concluded. X-ray treatment has been carried out at Memorial Hospital, New York City, in cooperation with Mr. L. D. Marinelli. A positive answer has been obtained concerning questions (1) and (2). The rate of production of dominant lethals at small doses is higher than the rate of production of cytologically detectable aberrations and is very nearly proportional to the dose. Experiments to test point (3) are still in progress.

DELAY IN REATTACHMENT OF CHROMOSOME FRAGMENTS

The study of Bauer, Demerec, and Kaufmann of X-ray-induced chromosomal alterations in *D. melanogaster*, reported in Year Book No. 37, suggested strongly that the production of such rearrangements involves a mechanism in which breakage precedes reunion (the hypothesis of Stadler) and not one in which breakage and reunion occur simultaneously as part of a single process (the hypothesis of Serebrovsky). In order to determine the duration of any interval occurring between breakage and reunion, Dr. Kaufmann has compared the effects of a given dosage administered to the sperms by intermittent treatments with the effects produced by an equivalent dose administered continuously. The results of the treatments were measured by salivary-chromosome analysis of the frequency of induced breaks, and by determination of the types of rearrangement produced. The values obtained for the fraction treatment should be lower than those for continuous treatment if in the interval between successive treatments some of the induced breaks "heal" to restore the original sequences and are therefore unable to participate with subsequently produced breaks in the formation of new arrangements. Moreover, if recombination occurs between successive treatments, the fractionated dose would be expected to produce a higher proportion

of the simpler rearrangements than the controls, and also a dearth of the types having many breaks involved in a single complex rearrangement.

The results of the experiment indicate that these differences do not exist. The close correspondence between the fraction and continuous treatments with respect to the numbers of breaks participating in new combinations suggests that no appreciable amount of "healing" occurs in the interval between successive treatments, even when that interval extends over a period of 16 days. Furthermore, the presence of multiple-break, complex rearrangements following the fractionated dosage strengthens the evidence for the theory that breakage precedes recombination. The question remains open concerning the nature of the physical and chemical processes which permit breaks or potential breaks to retain their capacity for reunion over a period of several weeks.

TERMINAL DEFICIENCIES

In the course of a study of the yellow-scute region of the X chromosome, three new deficiencies were found by Dr. Sutton in which the terminal bands of the X appeared to be missing. One of these was a spontaneous change which lacked the two distal bands, the second was a similar X-ray-induced change, and the third was an induced change lacking ten bands. In the latter a nucleolus-like structure was present at the broken end. Irradiation of sperm which carried this deficient X chromosome (balanced by a duplicating fragment) showed that the broken end does not tend to reunite with newly broken ends, and must therefore have been reconstituted as a normal end.

Two X-4 translocations with free broken ends were also found. In both cases the distal part of X, extending to the white-Notch region, was attached to the chromocenter of the fourth chromosome, while the distal part of the fourth was lost and the proximal side of the X break remained unattached. The unattached end in one of these stocks carried

a nucleolus-like structure similar to that described above, but smaller.

The interpretation, based on cytological observations, that these five changes involve failure of attachment and subsequent "healing" of broken ends is consistent with the genetical data, and the assumption of a permanent and indispensable but invisible "telomere" structure is considered unnecessary.

UNEQUAL BREAKS IN SISTER CHROMATIDS

A cytogenetic study has been made by Drs. Demerec and Sutton of an induced change at the Notch locus which arose from unequal breaks in the two sister chromatids of the X in the irradiated sperm. In one strand the

but near together, and second, the change in the *rst* locus four bands distant from one of the breaks—suggests that these phenomena were induced together as the result of a single electron hit. The region affected is about 1.5 microns long in salivary chromosomes, and is condensed to about 150 Å in the sperm. The spread of the physical excitation phenomena over such a distance is not contrary to physical expectation.

EXPERIMENTS WITH ULTRAVIOLET RADIATION

In cooperation with Dr. A. Hollaender, of the National Institute of Health, Bethesda, Maryland, Dr. Demerec has made a study of the effect of monochromatic radiation on the

EFFECT OF ULTRAVIOLET RADIATION ON THE SPERM OF *DROSOPHILA MELANOGASTER*

STOCK	CONTROL		2280 Å		2650 Å		2950 Å	
	No. chromosomes tested	% lethals						
Oregon-R	3049	0.07	512	4013	0.30	2629	0.27
Swedish-b	1627	0.18	1112	0.36
Yellow-white	5822	0	258	3.88	1274	0.39

breaks preceded 3C8 and followed 3E5, resulting in a deficiency for the sixteen intervening bands. In the second strand the left break immediately preceded 3C7, while the right break coincided with that of the first strand, following 3E5; and the segment 3C7-3E5 was retained as an insertion in the chromocenter of the fourth chromosome.

From subsequent breeding of the F₁ female a hypoploid class with the X deficiency of the first strand was isolated, and also a hyperploid class with normal X chromosomes and the duplication 3C7-3E5 in the fourth chromocenter. Genetic tests showed that in the deficient chromosome the *dm* locus within the limits of the deficiency, the *fa* locus adjacent to the left break, and the *rst* locus, four bands to the left of the left break, were affected. The duplication, which included the *fa* and *dm* loci, resulted in mottling for these characters.

The coincidence of two rare occurrences—first, two chromatid breaks at different points

sperm of *D. melanogaster*. Males were treated by exposing the sperm in the testes through the abdominal wall. To decrease the thickness of the layer to be penetrated by the irradiation, abdomens of the flies were pressed to about 0.2 mm. Two wild-type stocks, Oregon-R and Swedish-b, and a mutant stock, yellow-white, were used.

Measurements of the penetration of different wave lengths were made by photometering the photographs taken by the ultraviolet microscope. These measurements show that a large portion of the abdominal wall transmits as much as 50 per cent of radiation down to 2500 Å in both yellow-white and wild-type flies.

In genetic tests the main effort was concentrated on the X-chromosome lethals. A summary of the results is given in the accompanying table.

These results indicate that genetic changes may be induced by monochromatic irradiation of 2280, 2650, and 2950 Å. Their fre-

quency, however, is very low and variable. In all experiments the dosage used was just below the one which injures and kills the flies. Apparently that dosage is too low for genetic changes.

In similar experiments Mackenzie and Muller report between 2 and 5 per cent of lethal changes. They used filtered radiation which is a mixture of the section of the spectrum between 2700 and 4000 Å. The energy value used by them was 2×10^{10} ergs per square centimeter, while we were not able to use more than 1.4×10^7 ergs per square centimeter. Although Mackenzie and Muller did not find any chromosomal rearrangements, our preliminary experiments made with males exposed to 2650 Å yielded one translocation among 116 sperms tested. The rearrangement occurred between the heterochromatic regions of chromosomes 3 and 4.

Preliminary experiments were conducted with the region between 3400 and 4000 Å (6×10^{12} ergs per square centimeter), with the infrared region between 7000 and 17,500 Å, and with the carcinogenic agent dibenzanthracene, which was fed to males before they were exposed to radiation of 3400 to 4000 Å. So far, a significant increase in lethals has not been observed.

EXPERIMENTS WITH NEUTRONS

A series of experiments were conducted with neutrons (1) to determine whether they are able to produce breaks in chromosomes, (2) to compare the frequency of neutron-induced breaks with the frequency of breaks induced by similar dose of X-rays, and (3) to determine whether there is any difference between neutron-induced and X-ray-induced breaks as far as their distribution along chromosomes and the change at the breakage point is concerned. The wild-type males of the Oregon-R stock were treated by Dr. M. A. Tuve at the Department of Terrestrial Magnetism, Washington, D. C., and the tests were carried on by Demerec, Kaufmann, and Sutton.

Dosages were measured with a Victoreen dosimeter, and it was estimated that in terms

of Zimmer's results our two exposures were equivalent to about 3000 and 4000 r-units of X-rays. This estimate was confirmed by using a portion of the treated males to determine the frequency of induced lethals and checking from this by use of the curves prepared by Zimmer and Timofeoff-Ressovsky.

The results indicate that neutrons are effective in inducing chromosomal rearrangements; that the frequency of breaks does not differ appreciably from the frequency induced by a similar X-ray dose; that breaks are distributed at random throughout chromosomes; and that changes at breakage points are similar to changes induced by X-rays.

TIME REQUIRED FOR DROSOPHILA MALES TO EXHAUST THE SUPPLY OF MATURE SPERM

Dr. Demerec and Dr. Kaufmann have endeavored to determine the length of time after irradiation during which males may be mated repeatedly without exhausting the sperm which was mature during the period of treatment. The effects of the treatment were measured by the percentages of larvae, pupae, and adults developing from the eggs laid by a female following a single copulation with an irradiated male. Failure of eggs to hatch in excess of the controls may be attributable in part to the production of dominant lethals and in part to the laying of unfertilized eggs. In order to determine whether eggs deposited by an impregnated female had been fertilized, 99 eggs were studied which had been laid by females shortly after mating with males which had been irradiated with 5000 r-units. Cytological examination indicated that only 1 of the 99 had not been fertilized.

In the experiments, males treated with 3000 r were mated repeatedly on the day of treatment, and on the 6th, 7th, 12th, and 19th days thereafter. A drop in the percentage of dominant lethals was not observed until the 19th day, indicating that the sperm which was immature at the time of treatment does not become available until sometime after 12 days. Fully mature sperm available for immediate transfer may become exhausted in

a few consecutive matings. Actual counts of the numbers of sperms transferred by a single male in four consecutive matings were 3215, 2518, 1996, and 1047. The relatively few sperms transferred in the later matings of a consecutive series may soon be exhausted by the female, since polyspermy is common in *D. melanogaster*. The data indicate that unfertilized eggs may then be laid. On the day following depletion of the sperm, new supplies are made available for transfer. If this occurs within 12 days of the time of irradiation, the new sperms show the same proportion of dominant lethals as those previously used. By the 19th day, however, this proportion has decreased considerably, indicating that sperms are then available which were immature at the time of irradiation.

CORRELATION OF LOCI IN MITOTIC AND SALIVARY CHROMOSOMES

The pronounced constriction seen in the left limb of the second chromosome of *D. melanogaster* in mitotic nuclei is not apparent in the salivary chromosome. With the aid of deficiencies and translocations, Mr. Hinton has made a comparison of this region in the mitotic and salivary chromosomes. It has been found that the region between the constriction and the centromere (about one-fifth of the length of the mitotic chromosome) is represented only by the most proximal part of division 40 of the salivary chromosome.

EYELESS ALLELS

A preliminary study has been made by Mr. Hinton on the interaction of some of the alleles at the eyeless locus in *D. melanogaster* (*ey*², *ey*^R, *ey*^D, *ey*^{D_{39k}}). The homozygous *ey*^{D_{39k}} eye is larger than the heterozygous. One dose of a dominant plus one dose of a recessive is more effective than the heterozygous dominant.

GROWTH OF TRANSPLANTS

The effect of the host upon growth of transplanted imaginal tissue has been studied

by Dr. Katherine S. Brehme in *D. melanogaster*, using optic disks of female larvae of two genotypes, differing in larval growth rate: Florida wild-type (puparium formation at 100 hours from hatching) and Minute-w isogenic with Florida (puparium formation at 144 hours). When disks of larvae 76 hours after hatching were transplanted into hosts of the same age, it was found that the length of the interval between transplantation and puparium formation of the host is an important factor in determining the number of facets formed by the transplanted disk. Transplants were then made 36 hours before pupation of both donor and host. This series is not yet complete, but indicates that there is no effect of the + and Mw host tissue upon the growth rate of transplanted tissue of the other genotype. The data for wild-type disks in Mw hosts of the same age further indicate that increase in cell number is still occurring in the late third instar; this was confirmed by acetocarmine smears of wild-type optic disks of larvae just before pupation, which showed numerous mitoses. A comparative study of the development of Minute larvae has shown that although the first and second molts, 70-hour change, and puparium formation are delayed proportionately to the total prolongation of the developmental period of Mw, MFl^a, and Ml^b, the second molt and 70-hour change of Mn are delayed so greatly as to be disproportionate to the total length of development. This result and the finding that the growth curve of Minute larvae differs markedly from that of the wild type suggest that the larval development of Minutes is characterized not merely by a slowing down but by a qualitative difference from the wild type.

MODIFICATION OF CROSSING-OVER VALUES

A relation between the food intake of larval *D. melanogaster* and the frequency of crossing over in the resulting adults was established by Dr. James Neel, of Dartmouth College, guest investigator during the summer of 1940. Larvae developing at 26° C. were denied access to food during the last

one-third to one-quarter of larval life. Control larvae were allowed to feed freely until the time of puparium formation. The frequency of crossing over in the portion of the third chromosome lying between hairy and ebony-sooty (which includes the spindle-fiber insertion) was significantly higher in flies developing from partially starved larvae than in flies developing from control larvae. The increase in crossing over appeared to be uniformly distributed throughout the region studied. This is in contrast with the increase in crossing over observed to follow treatment with X-rays or extremes of heat, which is especially localized in the region of the spindle-fiber insertion. Coincidence values were not significantly different in control and experimental flies.

EFFECTS OF RADIATION ON ORTHOPTERAN CHROMOSOMES

Studies were carried on during the summer by Dr. J. Gordon Carlson, Rockefeller Fellow, on the effects of low X-ray doses on mitosis and chromosome breakage in the neuroblasts of the embryo of the grasshopper (*Chortophaga viridifasciata*). Treatment with 31.2 r

leads to a blocking of mitotic progress in cells in middle and late prophase. This results in a great increase in the number of cells in middle prophase and a disappearance of metaphases, anaphases, and early telophases. Recovery begins 3 hours after treatment, with a resulting increase successively in the numbers of late prophases, metaphases, anaphases, and telophases, all of which eventually considerably outnumber corresponding stages in untreated controls. These shifts in the numbers of cells in different mitotic stages is interpreted, not as a primary inhibiting followed by a subsequent stimulating effect of X-rays, but merely as a blocking and accumulation of cells at middle prophase followed by a recovery that allows these cells to pass simultaneously into successively later stages.

Neuroblasts exposed to 7.8, 15.6, 31.2, and 62.5 r of X-rays showed in the succeeding anaphases and telophases numbers of free chromosomal fragments that were directly proportional to the dosage in r-units. The linear proportionality suggests that the X-ray-induced chromosomal break resulting in fragment formation is produced by a single ionization or excitation.

EXPERIMENTAL LEUKEMIA

E. C. MacDowell, J. S. Potter, M. J. Taylor, E. N. Ward, and T. Laanes

From a broad point of view, the work on mouse leukemia may be considered a part of the general problem of the mechanisms by which heredity controls development—a problem to the solution of which the mouse colony of this department has long been devoted. The hereditary defects in development under observation in this colony that produce dwarfism, blindness, twisted jaws, and special behavior patterns represent temporary lack of normal developmental control, while in leukemia this lack of control is prolonged indefinitely. Leukemia, however, is sharply distinguished from other strain characteristics in one essential feature, namely, in that the time of appearance of the condition is not uniform. Dwarfism begins to be clearly manifest at 2 weeks; blindness at birth; twisted jaws at

early maturity, and behavior patterns as soon as free activity begins. But the onset of leukemia does not depend upon the attainment of a given age. Litter mates presumably of the same genetic constitution that live out their lives in the same box may vary as much as 16 months in time at which leukemia appears. This raises the question, What are the factors that determine the differences in the time of appearance of leukemia in mice carrying the same genes?

Further evidence of influences outside of genes has been previously reported. Some special maternal influence is indicated by the significantly higher incidence of leukemia in hybrids when the mother instead of the father contributes the heredity from the inbred leukemic strain. But when contributed by

fathers alone, the heredity from the leukemic strain in the first hybrid generation and in the backcross to the non-leukemic strain calls forth leukemia in proportion to the amount of total heredity from the leukemic strain. This is true under the conditions of this colony. But how far is the leukemic contribution even of fathers in fact a matter of genes, and how far of some material outside of the genes?

INHERITANCE OF SPONTANEOUS LEUKEMIA

We have repeatedly stressed the point that the incidence of leukemia (or indeed of any spontaneously occurring tumor) in a segregating generation cannot give proof of direct gene action as long as an unknown degree of nongenetic influence is operating. Unfortunately the maintenance of the same general external conditions for different generations does not warrant ignoring the extrinsic variables, for it appears that the *effective* influence of the same external conditions changes as the strength of the leukemic inheritance is reduced by outcrossing. Even in the same generation the effective impact of the seemingly uniform environment appears to differ for different individuals. This appears in the purebred leukemic strain, in which, in spite of uniform heredity, 10 per cent of the mice fail to develop leukemia; and again in the first hybrid generation of the cross between the leukemic and non-leukemic strains. Since each strain is genetically uniform, all the hybrids carry the same gene complex, and yet in the given environment leukemia appears in less than half of the animals. For both purebred strain and hybrids, extrinsic influences vary sufficiently to decide for each individual whether or not leukemia is to appear. The number of cases of leukemia is an index of the variability of the nongenetic influences; the incidence of leukemia tells how often the particular conditions occur that are necessary to develop leukemia from the given inherited tendency. Clearly the particular conditions necessary to develop leukemia with the total leukemic inheritance occur much more frequently than, and are different from, those

required when the total leukemic inheritance is reduced by one-half in the hybrids.

Thus in the backcross, in which all the existing genes segregate in different combinations in different mice, it is impossible to say whether the reduction of the incidence of leukemia to about one-quarter that in the purebred leukemic strain is due to the genetic diversity of the different mice or to the still greater infrequency of the particular conditions necessary to develop leukemia when the total leukemic inheritance is reduced to one-quarter. The second case implies "inheritance" transmitted outside of genes.

This is the old problem of disentangling two unknown variables. The only available method of distinguishing genetic and non-genetic variations is the breeding test. The principle of classifying an animal in a backcross or other segregating generation on the basis of the characteristics of its offspring instead of upon its own traits is simple enough. A single individual meets a single set of extrinsic influences; its offspring in sufficient numbers will experience a random sample of the entire range of possible sets of extrinsic variations, so that in the comparison of different families the influence of extrinsic variations is eliminated. But however simple in theory, in practice such an experiment, dealing with the natural occurrence of a malignant growth that may not appear until the third year, becomes a formidable undertaking. Such an experiment has never before been carried out, and conclusions in terms of a given number of genes are still being offered, in all seriousness, upon the incidence of tumors in the individuals of a segregating generation.

Indeed, one author seems to be so impressed with the possibility of interpreting our published results on the incidence of leukemia in the first hybrid generation and backcross by assuming a single gene, that he has credited us with concluding that one gene is the explanation, entirely ignoring the fact that, as we pointed out, many other interpretations are equally supported by the data, so that no conclusion as to the activity of any gene or genes is permissible.

SECOND BACKCROSS EXPERIMENT

In March 1937 a mating was made between a single male from our leukemic strain and three females from the non-leukemic strain, StoLi. This was the first step toward the analysis of the inherited basis of spontaneous leukemia in a backcross generation by means of breeding tests in the second backcross generation. The maternal influence was eliminated by transmitting the leukemic inheritance exclusively through males: through a single purebred male, through 7 of his hybrid sons, through 50 of his grandsons in the first backcross generation to his great-grandchildren in the second backcross. This study asks questions about the 50 backcross males, although the primary observations are made upon their offspring. The mothers throughout were from the purebred strain StoLi.

Since the elimination of the effects of extrinsic variables was the primary object of this experiment, it was important to raise the fifty families in the second backcross at the same time, so that, whatever uncontrollable variations in external conditions might appear from season to season throughout their lives, all families would be equally influenced. Thus the mice in the second backcross were born in the early winter of 1937.

The program called for autopsies of 50 offspring from each of the 50 backcross males, but in order to compensate for early deaths and autopsies undiagnosable on account of post-mortem changes, as many as 60 or more per family were actually produced. To breed such a large number of mice in such a short time and hold them until natural death led to many large-scale operations. This experiment more than doubled the normal size of the colony and required the complete equipment of a large new room. The climax of many months of preliminary breeding and other preparations was reached on September 21, 1937, when 500 StoLi females were mated with the backcross males. At the same time nearly 400 B.albino females were mated with B.albino males, so that large second-backcross litters could be distributed to two or more nurses and the StoLi mothers remated on the

day of parturition. Ten StoLi females were assigned to each backcross male; in making up these matings the 500 StoLi females were arranged in series according to their pedigree numbers (order of birth) and dealt out, one by one, to the 50 backcross males in rotation, thus distributing as equally as possible any influence of differences in the females due to age or litter. To facilitate breeding, all these females were observed daily and only those in some stage of oestrus were left with their mates. According to the usual practice, every pregnant female, both StoLi and B.albino, was isolated.

Promptly on October 10 the deluge of births began. Within a week 1067 second-backcross animals were born. B.albino foster mothers were ready to care for all of these. Later the supply of B.albino foster mothers was exhausted, but StoLi mothers in matings that first completed their quotas soon became available to assist in nursing large litters. By August 30, 1940, the last mouse in this experiment was autopsied.

The gross autopsies were mostly made by Miss Taylor, with assistance from Mrs. L. Cason during the summer of 1939. The monumental task of preparing slides for microscopic diagnosis has been carried single-handed by Miss Ward; this work has been completed for deaths through October 1939. Although the histological diagnoses are incomplete, the agreement between diagnoses based upon gross autopsies and upon sections has been so close that a preliminary summary of results at this time will give an unquestionable indication of one important conclusion.

The frequency distribution of the 50 second-backcross families according to the incidence of leukemia within each reveals the required information. If one gene has a primary role, the families should be divided into two equal groups, one close to 0 leukemia, the other group centered about 22 per cent leukemia per family. Some years ago we reported a parallel second-backcross experiment used for the analysis of the inherited basis of natural susceptibility to transplanted

leukemia of line I. In that experiment the respective second-backcross families from 50 backcross males, when tabulated according to the proportion of individuals proved susceptible by inoculation with line I leukemia, did in fact form such distinct and equal groups; 25 families were close to 0 susceptible and 25 were symmetrically distributed about 50 per cent. In the present case the preliminary classification of the 50 second-backcross families according to the percentage of spontaneous leukemia shows no such division into two groups, nor does the polygon of the frequency distribution even suggest any bimodality, but rather a continuous series from 0 to nearly 30 per cent with an intermediate mode. This eliminates the possibility of interpreting the results for spontaneous leukemia on the basis of one outstanding gene and justifies our previous caution in drawing conclusions in the absence of such critical evidence. Further conclusions must await the final figures.

Such a large collection of materials and records permits analysis from various points of view. Pathologically, the incidence of malignant growths other than leukemia and a marked shift in the relative frequency of lymphoid and myeloid leukemia promise significant contributions. With regard to the factors influencing the actual manifestation of leukemia, certain heterogeneities in the data demand study of the correlations between such recorded information as length of life, sex, 8 classes of coat color, date of birth, strain of nurse, position of box, and age of mother.

SITUS INVERSUS VISCERUM

Situs inversus viscerum, though known in man and fish, appears to be very rare, if known at all, in any laboratory mammal. Miss Taylor's discovery of four cases among the mice of one strain is therefore worthy of notice. In the course of the past ten years, autopsies have been performed upon an estimated number of 50,000 mice from the highly inbred strain C58. Among these, the four cases of s.i.v. were closely related in the 51st

and 52d generation of brother-by-sister inbreeding; three cases came from the same father by three of his sisters, while half-sibs (same father by different sisters) of these parents were the grandparents of the fourth case. Since all the mated animals of this strain have been autopsied, it can be stated that in none of the ancestors of these cases was the position of the viscera reversed. The mothers of the four cases produced, as well, a total of 38 mice normal at autopsy. Unfortunately the breeding of this particular branch of the strain was discontinued before its interest became known, so that no study of the possible hereditary nature of this anomaly is possible. In man, twenty-four instances of s.i.v. in two or three members of the same fraternity have been reported, as well as two instances in parent and offspring, and four instances in more distantly related individuals.

COOPERATION

In approaching the broad problems opened by the studies on leukemia, progress depends in no small measure upon opportunities to utilize an increasing range of biological techniques. In most cases these have become so specialized and form such separate fields that cooperation between men and laboratories already thoroughly equipped, however difficult in view of the competitive element in research, offers the possibility of economical and effective procedure when the give and take in such cooperation is well balanced. For this reason the opportunity for three tentative cooperative undertakings during the year has special importance.

Clinical interest in the effect of certain extracts upon leukemic cells, and of reduced oxygen pressure upon mice inoculated with leukemic cells, initiated two series of experiments carried out in cooperation with investigators in the New York University Medical School and in the Department of Practice of Medicine of the College of Physicians and Surgeons. The third laboratory was the Rockefeller Institute for Medical Research, where Dr. A. Claude has been studying extracts of normal and malignant tissues ob-

tained by high-speed centrifugation. A certain "heavy fraction" has special interest. It has now been found that an unusually high yield of this heavy fraction can be obtained from the tissue of mice infiltrated with transplanted leukemic cells of two of our lines. This arouses Dr. Claude's interest in our material; on the other side, a preliminary test of the physiological activity of this "heavy

fraction" as an inducer of resistance to leukemic cells indicates that Dr. Claude's technique of extraction may have valuable uses in the analysis of the various phenomena of resistance which we have been investigating. Though as yet unconfirmed by large numbers, it is of interest that this preliminary test gives the first evidence of any physiological activity of an extract of leukemic cells from our lines.

ENDOCRINE STUDIES

*O. Riddle, R. W. Bates, R. A. Miller, E. L. Lahr, G. C. Smith,
H. H. Dunham, and D. F. Opdyke*

To study the regulation of reproduction, growth, and development, one studies the anterior pituitary gland; and to study that gland, one gives much attention to several other organs and glands, such as adrenals, ovaries, blood, pancreas, and thyroids. A report of progress in a study of hormonal regulation of either reproduction or development will therefore include items from a series of organs and functions. Our opportunity to examine some mechanisms centering in the pituitary gland has been much extended by a grant from the Carnegie Corporation of New York to the Carnegie Institution of Washington.

PITUITARY INFLUENCE ON SIZE OF BODY AND VISCERA

Previous reports have noted that in hypophysectomized pigeons prolactin is largely responsible for sustaining or increasing body weight and for overgrowth in visceral organs (splanchnomegaly). Two associated effects, hitherto unrecognized, have been observed by Schooley, Riddle, and Bates. Though the administration of all pituitary hormones (whole pituitary extract) entirely fails to sustain or increase the weight of the pancreas in completely fasting pigeons, it now appears wholly probable that at least two pituitary hormones, prolactin and thyrotropin, under normal feeding conditions serve to sustain or increase pancreatic tissue. The evidence is derived from numerous groups of variously treated pigeons—448 hypophysectomized and

119 normals—of the same age, source, and race. Groups injected with either prolactin or thyrotropin, if not fasted, invariably conserve more pancreatic tissue than groups left untreated. Extra large pancreases, however, are found only in birds injected with preparations which stimulate both their thyroids and crop sacs. This fact provides reason for assuming that it is thyrotropin which (like prolactin) actively supports the pancreas, but it is entirely possible that the active agent is another (pancreatropic) hormone till now unseparated from thyrotropin. Although these hormones act partly through increasing appetite and food intake, the force-feeding of hypophysectomized pigeons only partially sustains their pancreatic tissue. This association of prolactin and thyrotropin derives additional interest from the fact that these two hormones were already known to show two synergistic actions: increasing the rate of heat production in doves, and promoting the growth response in dwarf mice.

A second item disclosed by this study is of somewhat similar nature. When prolactin is injected into pituitaryless pigeons for as much as 10 days, the magnitude of its effect upon the weight of the crop sacs depends upon the state or purity of the prolactin. If it is in the form of purified prolactin the maximum weight attained by the crop sacs will be much less than if it is in impure, or unseparated, form. Here again one observes that some other now unidentified product or products of the pituitary enhances or synergizes the

action of prolactin in birds deprived of their pituitary glands. This does not occur in normal birds.

The two above-mentioned items tend to support the general view we have earlier expressed concerning the mechanism through which the pituitary gland promotes growth. According to this view, more than one now known anterior pituitary hormone assists bodily growth; any one such hormone may be of greater or less influence in one species than in another; and prolactin has special importance to growth in pigeons.

Several years ago a study by Bates, Laanes, and Riddle demonstrated that when water-insoluble (prolactin) and water-soluble (gonadotropin and thyrotropin chiefly) pituitary extracts were combined there was augmentation or potentiation of the growth effects invoked in dwarf mice. Because this potentiation of the two fractions upon recombination was of the order of 10 to 20 times, an extrapolation based upon the quantitative relation between weight increment and dosage was required for its estimation. In order to test the assumption of a similar quantitative relation for a recombination of pituitary hormones, 15 dwarf mice were injected at several dosage levels with equal weights of a prolactin preparation (no. 680) and a water-soluble fraction (no. 549). The dosage varied from 0.0005 mg. to 1.0 mg. of each per day. The lowest dosage (on 2 mice) caused a 30 per cent increase in body weight in 30 days; the highest dosage (on 1 mouse) caused 114 per cent increase in body weight in 30 days. The whole body of new data confirms the assumption that the quantitative relation between dosage and percentage increase in body weight is independent of the particular pituitary extract injected. The enormous sensitivity of this growth response is indicated by the fact that only 0.001 mg. daily, or a total of 0.03 mg. in 30 days, of the recombined fractions was sufficient to cause measurable growth in the dwarf mouse.

ASSAY OF PITUITARY HORMONES

Accurate knowledge of pituitary hormones is highly dependent upon accurate methods

of assay. This laboratory assumes a special obligation to study conditions affecting the assay of prolactin. We have earlier measured and described the effect upon the crop-sac response to prolactin of age, sex, race or strain, fasting, route of injection, volume of fluid injected, number of daily injections, and the duration (number of days) of injections. Possible effects of season have hitherto been neglected by us and others, though personal correspondence has indicated that some laboratories suspect that assay values vary seasonally. Bates, Riddle, and Lahr have now measured the rather serious effect of season upon the assay of prolactin.

At 6-week intervals during the past two years groups of 10 immature White Carneau pigeons were injected (0.5 mg. per day of prolactin for 4 days) with a freshly made solution of the same prolactin powder, in order to determine the effect of season and to learn the reproducibility of assay values. The crop-sac weights were found to vary in a rather regular manner throughout the year. At two periods, one in April-May and the other in October-November, the crop-sac weights were smallest, about 2600 to 2900 mg. During the remainder of the year most of the values approximated 3600 to 3900 mg. The highest and lowest weights found, when converted into terms of units per milligram of the preparation used (no. 657), represent seasonal changes in responsiveness of 4.4 times (5.3 to 23.3 units). Changes of this magnitude were not anticipated, but the results of a first year of study were fully confirmed both as to degree and as to time of occurrence by data obtained during a second year. These changes seem to bear no simple relation to temperature or light. Though the cause of the fluctuations is not clear, the knowledge of their existence is of practical importance in the assay and study of prolactin.

The local crop-sac method, or micro-method, of testing for prolactin (intracutaneous injection over the pigeon's crop sac), introduced by Lyons and Page a few years ago, is currently used in some laboratories for detecting and measuring prolactin in blood and urine. Almost nothing has been

published on the reliability and specificity of the method. In a study of this question Bates, Lahr, and Riddle find that many non-pituitary substances, when injected intracutaneously over the crop, stimulate cell division in the lining of the pigeon's crop sac. In the present tests, single 0.5-ml. injections were regularly used with autopsy after 48 hours. All birds were injected with colchicine 7 hours before killing, so that mitotic counts on crop sacs could be made microscopically as a check on macroscopic estimation of growth.

Ulceration, with visible thickening and high mitotic counts at margins, was caused by 30 per cent ethanol or acetone, 1 per cent formaldehyde, 3 per cent cresol, trypsin (20 mg.), 1 per cent ammonia, and strongly acid or alkaline solutions. Lower concentrations of most of these same substances caused cell proliferation without ulceration, for example, 10 per cent acetone or ethanol, 5 per cent butanol, 0.1 per cent formaldehyde, 0.1 per cent ammonia, 0.01*N* HCl or NaOH. Other substances giving good stimulation were tannic acid (2 to 5 mg.), pyrogallol (2 to 10 mg.), histamine (2 mg.), Sudan Black (2 mg.), quinhydrone (10 mg.), and bile (0.01 to 0.1 cc.); ascorbic acid (10 mg.) and thiamin (1.0 mg.) increased mitotic counts. Of various steroids in sesame oil, testosterone (1 mg.), androsterone (1 mg.), and progesterone (0.4 mg.) were positive; stilboestrol (0.15 mg.), estrone (0.5 mg.), and desoxycorticosterone acetate (1 mg.) were negative. Casein, muscle extract, and hemoglobin were negative at a 10-mg. dose level. Threads passed through the crop wall caused local thickening and cell division.

Many of these substances were ineffective, and none of those tested were effective, in producing crop-sac stimulation when injected systemically. The response observed with the many non-pituitary substances is probably partly ascribable to cell products formed in irritated skin at the site of injection. Such substances as acetone, alcohol, and ammonia may, however, be directly and alone responsible for the proliferation and ulceration

observed in these tests. Since many intra-dermally injected substances other than prolactin can thus stimulate the crop epithelium, this micro-test is valuable only when used with care.

A method for assaying pituitary extracts and preparations for their adrenal stimulating potency (adrenotropin) on 2-day chicks has been developed by Bates, Riddle, and Miller. Chicks are injected subcutaneously daily for 5 days. The total amount of a pituitary preparation required to increase adrenal weight by 25 per cent when injections are made thrice daily, or one-half the amount required for a 25 per cent increase when injections are made only once daily, was selected as the unit of adrenotropic or corticotrophic activity. In chicks, as in rats, adrenal weight increases in proportion to the first power of the dosage. Potent preparations induce both hypertrophy and hyperplasia of cortical cells.

Non-pituitary substances, either hormonal or otherwise, when administered by injection at nearly lethal dosage levels cause little or no enlargement of the adrenals of these chicks. The substances tested were thyroxin, insulin, estrone, dihydroestrone, testosterone, desoxycorticosterone, formaldehyde, ammonia, casein, zinc and copper sulfates, and potassium chloride. Thyroidectomy did not alter the degree of the adrenal response even when pituitary fractions with high content of thyrotropin were used. Hypophysectomy did not prevent adrenal enlargement, although it tended to decrease the degree of the response.

Largely in consequence of advantages possessed by this method of assay, it has also been possible to develop a method of preparing highly potent adrenotropic fractions essentially free from prolactin, thyrotropin, and FSH (the relationship of LH to "adrenotropin" is uncertain). The method is based on solubility in 60 per cent ethanol and at pH 3.5 in water, with subsequent division of the pH 3.5 extract into soluble and insoluble fractions by dialysis.

Micro-colorimetric methods for N, P, Ca, glucosamine, and carbohydrate have been

modified by Dr. Bates to fit our equipment and material. Routine measurement of the tryptophane, glucosamine, and carbohydrate content of anterior pituitary fractions helps to characterize and differentiate them. As first shown by Evans and associates, it is found that the glucosamine and carbohydrate content varies from 0.5 per cent for prolactin fractions up to over 8.0 per cent for gonad-stimulating fractions. On the other hand, the tryptophane content varies from 0.5 per cent for gonad-stimulating fractions to 1.6 per cent for prolactin fractions.

In these and other studies much technical assistance was given by Mr. Dale Hennon and Mr. Louis Stillwell, Jr.

PITUITARY-ADRENAL-GONAD RELATIONS

Further study of the effects of extra-pituitary substances upon size and cytological changes in adrenals of normal and hypophysectomized pigeons was carried out by Miller and Riddle. Thyroxin, estrone, stilboestrol, and insulin have all been found to have a stimulating effect upon the adrenal cortex; desoxycorticosterone acetate, however, depresses the adrenal, reduces its weight, and gives a cytological picture essentially like that found in hypophysectomized birds.

Thyroxin has but little effect upon the adrenal. In normal animals, only high doses (0.150 mg. daily) are effective in stimulating cortical cells; in hypophysectomized birds, a dosage which is just sublethal (0.050 mg. daily) gives cytological evidence of stimulation, though it is only partially effective in maintaining adrenal weight. Estrone is more effective than thyroxin, possibly because it may be injected in higher dosage; but neither these nor other agents (with the exception of gamone) are nearly as effective as is insulin in stimulating the adrenals of birds. This extraordinary potency of insulin probably rests on already recognized relations of pancreas and adrenal in carbohydrate regulation, and may also be regarded as a special expression of the fact (noted by Riddle seventeen years ago) that the pigeon successfully resists enormous doses of insulin. It

thus appears that the pigeon adrenal responds to a number of substances other than pituitary adrenotropin.

An important difference between the response of the adrenal to certain pituitary extracts and to hormones of extra-pituitary origin is that with the former the response is greater in the normal than in the hypophysectomized bird; with non-pituitary hormones, however, hypophysectomized pigeons show greater stimulation and are stimulated by lower levels of dosage than normals.

During the present year a technique for removing the adrenals of pigeons has been improved by Dr. Miller. The glands are dissected out, not cauterized; in some instances they are removed without tearing the capsule and the completeness of the operation is thus assured.

Two unexplained actions of desoxycorticosterone acetate and progesterone on reproduction have been observed and are still under study by Dunham and Riddle. Both of these hormones, when injected in oil (0.1 to 0.5 mg.) or implanted as pellets in doves a few hours prior to ovulation, prevent normal ovulation; and when injected soon after the entry of an ovum into the oviduct, they greatly reduce the amount of shell deposited upon the forming egg. Results to date indicate that in high dosage androgens have nearly equivalent effects. In very high doses (1.0 mg.) estrone similarly injected may also sometimes inhibit ovulation, but no thinning of shells occurs. At the moment the point of chief interest is that desoxycorticosterone and progesterone have a similar action and a high effectiveness in disturbing two phases of reproduction in the bird. It is becoming known that in still other ways these two products of the adrenal and ovary produce similar effects.

The immature pigeon testis is generally recognized as a sensitive assay object for gonadotropic hormones, but there is some doubt as to whether its response is to FSH, LH, or both of these hormones. Since the testis is composed of two specific tissues, germinal (tubular) and interstitial (inter-tubular), and these two types of tissue are

apparently under the influence of different pituitary hormones—FSH and LH, respectively—it becomes of interest to know how these two types of tissue develop under normal conditions and also under experimental conditions which force them to complete their entire development within a few days instead of months. Lahr and Riddle have completed such a mensurational study on testes throughout the range of normal development, and also after 4, 8, 12, and 16 daily injections of FSH (or LH).

It was found that in 2-month-old pigeons the very minute testes are composed of 50 to 60 per cent intertubular tissue and 40 to 50 per cent tubular tissue. During the next 6 weeks the intertubular tissue develops more rapidly and attains 60 to 70 per cent of the total. Thereafter intertubular tissue develops slightly or not at all, although tubular tissue develops markedly and becomes 80 to 90 per cent of the testis. When all these phases of testis development are forced to proceed to completion and sperm production by 12 to 16 daily injections of FSH, the nature and sequence of the changes which occur in the two types of tissue are quite parallel to those of the normal series. This parallelism suggests that FSH, not LH, normally plays the chief part in the development of the bird testis. Our few tests with LH indicate that under its injection the intertubular tissue develops in higher percentage than normal (as reported by Greep and Fevold), and apparently persists to an unusual degree, though it ultimately attains a condition comparable with that attained under FSH.

HORMONES AND RESPIRATORY METABOLISM

Recent experience of others in the maintenance of adrenalectomized animals in fair or good condition without use of cortical hormones gives new interest and value to measurement of the basal metabolism of such animals, and the adrenal-pituitary relation is now the subject of active study in several laboratories. The pigeon has been found useful in such studies and is apparently able to survive complete adrenalectomy with only

moderate care. Repeated metabolism measurements by Riddle and Smith on a number of such pigeons indicate that this operation has little or no effect (—6) on heat production, and does not destroy the ability of prolactin to increase the basal metabolic rate. The required additional study of these topics is in progress.

It is well known that either fasting or hypophysectomy causes a very marked decrease in rate of heat production in various animals, including pigeons. Two years ago we reported a few measurements made at 30° C. on small groups of normal and hypophysectomized young (2-month) pigeons fasted continuously for 10 days, which gave the wholly unexpected result that heat production was decreased less in the operated than in the normal birds. In other words, when these two means of depressing the metabolism are combined, the depression is less than when only one of them is employed. Further study has now shown that this result is obtained from measurements made at either 25° or 30° C. In these tests fasting is begun immediately after hypophysectomy, and at either temperature the metabolism of normal birds continues to decrease to the end of the 10-day period, but in operated birds there is very little decrease after 72 hours. For example, in measurements made at 25° C. on normal birds the values obtained at 6, 8, and 10 days of fasting were lower than their 3-day values by 10, 14, and 18 per cent. In operated birds, however, the losses at comparable periods were only 3, 7, and 10 per cent.

RELATION OF PITUITARY TO CARBOHYDRATE AND FAT METABOLISM

Within the past decade it has become increasingly clear that one or more pituitary hormones are able to modify greatly the disposition of carbohydrate and fat by the body. The identity of those hormones remains uncertain. In connection with the very large amount of fractionation and painstaking assay of pituitary preparations currently performed in this laboratory, it has long been evident that many of our variously assayed

and carefully studied preparations should also be examined for their effects on the metabolism of carbohydrate and fat. During the past two years, with the aid of a grant from the Committee on Research in Endocrinology, National Research Council, these pituitary preparations and still other hormones have been employed thus in a productive program of study.

Since a rather extensive report was rendered last year, the present statement on this study by Riddle and Opdyke is brief. The consideration given last year to the hormones

show that gonadotropin (mare serum and some FSH+ preparations) will effectively stop or block maternal behavior after it has become established either normally in a "control reactor" or by injections of prolactin or other hormone. It is notable that though prolactin leads all other substances in effectiveness, 4 quite different hormones or substances—progesterone, testosterone, intermedin, and phenol—also have quite pronounced positive action. It is not yet known whether all these substances cause a release of prolactin from the rat's own pituitary gland.

"MATERNAL" BEHAVIOR INDUCED IN YOUNG RATS BY HORMONES

(The values given represent percentage of rats responding positively; numbers within headings indicate the number of tests)

Sex	Control reactors (1205)	Prolac-tin 197	Proges-terone 99	Testos-terone 70	Inter-medin 71	Whole A.P. 117	FSH and thyro-tropin 49	Phenol 69
Females.....	(22)	71	68	62	59	51	14	46
Spayed females.....	(25)	79	65	84	60	20	0	54
Males.....	(21)	57	58	4	46	9	18	25
Castrated males.....	(20)	80	65	52	80	17	10	75

which induce lipemia in pigeons should be supplemented by the later-learned fact that estrogens effectively increase the blood fat in the absence of the pituitary, adrenals, or pancreas.

HORMONAL BASIS OF MATERNAL BEHAVIOR

Previous reports have noted progress in a rather prolonged study of the relation of hormones, prolactin in particular, to the initiation of maternal or parental behavior in adolescent female and male rats. The experimental part of this study conducted by Riddle and Lahr has been completed, but an analysis of the 2770 tests made during a five-year period is unfinished. In general, the final results confirm our report of two years ago, and a discussion of the subject will not be repeated. In the accompanying table, however, a summary of results obtained with 7 of the 19 substances tested on four types of rats is given. Other data not tabulated would

Another study by Lahr and Riddle assists an understanding of an aspect of maternal behavior in virgin rats. Eleven virgin female rats were treated with estrogenic hormone for 20 to 26 days; 5 of these received estrone in the form of implanted pellets for 20 days, 5 received injections of 250 R.U. of estrone in oil for 20 days, and 1 received 100 R.U. estradiol benzoate for 26 days. Under this treatment the mammary glands of these virgin rats developed to a degree comparable with that found in the later stages of pregnancy, and traces of colostrum were present. When young rats were presented to these virgins during the last 3 or 4 days of dosage, the virgins gave them no care, but after dosage was discontinued all began to give full maternal care within 1 to 7 days. In 9 of these cases the females fed and reared 1 to 3 young to weaning; in the other 2 cases the young were temporarily fed or cared for but not reared.

The expression of maternal care as it first appears in these rats given long-term treatment with estrogens is identical with that which we have noted in our main study of maternal behavior in rats; and since, in the special tests described here, that expression quickly and uniformly includes suckling and rearing young (full maternal care), these tests confirm or justify our interpretation of the simpler behavior (carrying to nest; hovering) as truly "maternal" behavior.

PHYSIOLOGICAL DIFFERENCES IN TWO STRAINS OF FOWL .

In tests made on baby chicks for thyroid-, gonad-, and adrenal-stimulating activity of pituitary extracts, Bates and Riddle have used White Leghorn cockerels obtained from two different hatcheries in Indiana; birds from the two sources may be called *M* and *C* chicks.

All injections were begun 2 to 3 days after hatching, and the chicks were autopsied 5 days later. The unstimulated weight of testes and adrenals, and their increase in response to increasing dosage with gonadotropin and adrenotropin, respectively, were found to be nearly the same in *M* and *C* chicks. Also, the average unstimulated thyroid weight for both groups varied from 2 to 4 mg., and indicated no difference. The increase in thyroid weight in response to increasing thyrotropin dosage was, however, very different. Four times as much thyrotropin was required for threshold stimulation in *M* chicks as in *C* chicks, and this difference in dosage was maintained at levels of thyroid weight two and three times larger than the unstimulated weight. Again, the maximum thyroid weight attainable in *M* chicks was only about 15 mg., while 30- to 35-mg. thyroids were obtained with *C* chicks.

ANTHROPOLOGY AND HUMAN GENETICS

Morris Steggerda and Ruth Bate Eckardt

GROWTH OF CHILDREN

It has previously been reported that growth trends in stature for the four racial groups studied, Navajo, Negro, Maya, and Dutch white, are curiously the same. It was shown that in each of these races the annual increment decreases from 6.5 to 10.5 years of age, at which time the rate increases until 14.5 years, after which it rapidly falls. This is of physiological interest when one recalls that these four groups live in entirely different environmental conditions. During the present year the growth curves of 50 Zuñi children have been examined. The yearly increments of the Zuñi boys, most of whom have been measured for eight consecutive years, show a growth trend similar to that of the four previously mentioned races. The actual average increments in millimeters for Zuñi boys for the ages from 6.5 to 14.5 years are: 65, 57, 57, 48, 50, 53, 59, 65, and 62. This shows the lowest increments to be at 9.5 years and the greatest at 13.5, being one year earlier, for

both the low and high points, than in the other races mentioned. The trend, however, is very much the same in all five racial groups. Thus our data point to the conclusion that all male children have a minimum increment of growth at the age of 9 or 10. From this age to that of 13 or 14 they undergo a period of rapid growth, after which time the increment decreases.

ERUPTION TIME OF TEETH

Earlier work in this laboratory on the teeth of these four racial groups has shown a definite difference in the incidence of caries. It has been shown that the Navajo and Maya are about equally free from caries and have far better teeth for each age than do the Negroes or whites. During the present year an attempt has been made to analyze the data regarding the eruption time of the permanent teeth in each of these races. Most of the data in the literature concerning eruption time of teeth pertain to the white race. The present study

is unique in that it considers the development of at least 100 children from each of these four races, all of whom have been examined not once but over several consecutive years, some as many as eight and nine years. In one year the condition of tooth eruption was noted, and approximately one year later the same child was examined again by the same investigator. The environmental conditions under which these children live are extremely varied; thus, the Maya children are from Yucatán, the Navajos from Arizona, the Negroes from Alabama, and the Dutch whites from Holland, Michigan. The most interesting of these conditions is the wide divergence in food habits of the four races, since diet is considered a fundamental factor in determining the nature and growth of teeth. Since not only the environment but also the genetic constitution of the four groups is so unlike, one might naturally expect a corresponding dissimilarity in the eruption time of the teeth. Surprisingly enough, however, the pattern of tooth eruption is very similar in all these races, just as the pattern of growth was shown to be. From a preliminary study the following tentative results are noted:

First, the four races are alike in that the order in which the teeth appear is very much the same. For example, in each race the first molars appear first; they are followed by the central incisors, and then by the lateral incisors. The canines and the first premolars appear next and at approximately the same time; after them come the second premolars, thereafter the second molars, and finally the third molars. This order is similar to that given in the dental textbooks for whites, but has never before been shown to be true for four distinct races. A second similarity observed for the four racial groups is that the lower teeth generally erupt earlier than the corresponding uppers, with the exception of the upper first premolars, which erupt earlier than the lowers in all races but the Dutch, and the second premolars, about which no generalization can be made. Another uniformity observed is that there is no significant

difference in eruption time of the corresponding teeth in the right and left sides of the jaw. It was also noted that the sex difference is consistent for all races; that is, each tooth erupts earlier in the females than in the males. In these general respects the races behave very much the same. However, concerning racial differences our data show that the teeth usually erupt earlier in the Navajos than in the other three races, and also later in the whites than in the other groups. The differences between Navajo and Dutch eruption time are highly significant statistically.

CROSS SECTIONS OF HUMAN HAIR FROM FOUR RACIAL GROUPS

The unique device for making cross sections of animal and plant fibers invented by Dr. J. I. Hardy (*A practical laboratory method of making thin cross sections of fibers*, Circular 378, U. S. Dept. Agric., Washington, 1935) has the advantage over the old embedding and microtome technique that as many as 150 fibers can be sectioned at once. The device was invented primarily for use in the wool industry, but it can also be used for making cross sections of human hair. The time required for making a permanent slide containing 150 cross sections may be as little as 10 minutes, as compared with 2 or 3 days with the older technique. The technique outlined by Dr. Hardy was followed and somewhat refined in our laboratory. Miss Barbara Korsch assisted in making the slides and in measuring the cross sections.

The device is a small metal plate, 3 inches long, 1 inch wide, and $\frac{1}{8}$ inch thick. It has a narrow slot $\frac{3}{8}$ inch long into which can be packed 150 to 200 hairs, depending upon the thickness of the hairs and the degree of tightness with which they are packed. The hairs are washed in carbon tetrachloride, dried, and packed into the slot; then cut off even with the metal plate, on both the top and bottom sides of the plate; then pushed partly through the fiber slot by means of a metal screw. By turning the screw, the depth of the cross sections can be regulated. The layer of protruding hair tips is then coated with a thin

solution of celluloid (11 g. celluloid, 40 cc. acetone, and 20 cc. amyl acetate). When the solution, containing the hair sections, hardens, it is cut off with a sharp razor blade, and the resulting strip mounted in euparal or Canada balsam.

Hair samples were taken from ten individuals each of the Maya, Navajo, Dutch, and Negro races, and slides were made of all samples. The hair sections were drawn with a camera lucida; from the drawings measurements were made of the maximum and minimum diameters, and the area was determined with the aid of a planimeter.

The mean values for the area, maximum and minimum diameters, and the hair index (minimum/maximum \times 100) are listed in the accompanying table. It is evident that the

races, is as follows. A Maya had hairs ranging from 25 to 120 microns in maximum diameter; a Negro, from 20 to 130. These examples demonstrate the value of sufficient numbers.

TWINS

It was noted briefly in the last annual report that an analysis was being made of 26 pairs of twins of the same sex, to determine more specifically the use of anthropometry in diagnosing one- and two-egg twins. During the past year 9 more pairs of twins were measured. The total mean differences between twin pairs for 35 anthropological measurements were calculated. For each measurement, the mean differences were divided by the standard deviation for the

Race	Area	Maximum	Minimum	Index
Maya.....	14.7 \pm 0.13	76.4 \pm 0.36	64.6 \pm 0.27	85.3 \pm 0.21
Navajo.....	14.1 \pm 0.12	75.3 \pm 0.37	58.2 \pm 0.26	78.6 \pm 0.28
Negro.....	13.9 \pm 0.14	87.2 \pm 0.50	45.8 \pm 0.25	53.3 \pm 0.26
Dutch.....	9.4 \pm 0.08	63.5 \pm 0.33	46.3 \pm 0.21	74.6 \pm 0.29

Maya have the largest hair in cross section, and the Dutch the smallest, with the Navajo and the Negro approaching the Maya very closely. The Negro hair is the most elliptical, and the Maya is the roundest. These differences are statistically significant. This is the first time that racial differences in hair shape have been subjected to statistical analysis, a process which was previously impossible owing to the limitations of the old technique of hair sectioning. Besides making possible the statistical treatment of racial differences in hair, the new technique allows an analysis of the variation found in the size of the hair in any one individual and in any one race. This variation is found to be very great; for example, one Maya individual has a mean maximum diameter for 100 hairs of 59.6 microns, and another of the same race has 83.3. In Negroes, whose hair is most variable, the means range from 66.0 to 106.1 microns. The variation in the size of hairs of one individual is likewise great. An example of this, taken again from the Maya and Negro

measurement to obtain a standard score. The purpose of such a scoring was to express the difference in comparable units. These scores were then arranged in order of magnitude, that is, those twins most alike had the lowest score and were placed at one end of the scale, and those most unlike were at the opposite end. The first general fact observed was that there is no obvious point of demarcation that will invariably separate identical and fraternal twins. There seem to be degrees of similarity in identical twins as there are in fraternal twins.

As a matter of fact, it has been found that no one measurement is adequate to determine zygosity. For example, in most cases differences in stature have been small in identical twins, but there have also been instances when nonidentical twins have an equally small difference. Thus stature alone cannot be relied upon with certainty. Similarly, weight alone is not adequate, but when combined with stature and other measurements, it becomes a valuable criterion in twin diagnosis.

It was found that the larger the number of measurements used, the better anthropometry aids in separating twin types.

Among the measurements determined, it was found that certain ones are much better criteria of twin similarity than others. In this category belong weight, vertex height, suprasternale, chest girth, head length, and head girth; also good anthropometric criteria are sitting height, intercristal, lower leg, and foot length and breadth. Poor criteria are bizygomatic, ear height and breadth, upper arm, minimum frontal, bignonial, and hand breadth. Some of these measurements are listed as poor criteria because they are difficult to take, e.g., ear height and breadth. Others, such as bizygomatic and minimum frontal, although more accurately determinable, are not of much value since there is no association between the magnitude of the difference and the type of twins.

Another interesting fact learned concerning the growth of identical twins as compared with the growth of nonidentical is that the growth pattern remains practically the same

in both cases. Thus, the specific differences between twin pairs are usually maintained during their observed growth period. If an identical twin differs only slightly from his brother at 8 years of age, in succeeding years the same degree of dissimilarity is generally maintained. In fraternal twins the differences are often greater than in identical ones, but here also the magnitude of the difference remains the same throughout the years.

The time pattern of tooth eruption shows striking similarities among certain identical twins, as do the number and location of carious lesions. Thus these tooth factors are proving of great value in the diagnosis of identical and fraternal twins.

Data concerning the customary techniques of determining one- and two-egg twins, such as finger and palm prints, hair and eye color, photographs, personal traits, etc., are also available for these 35 pairs and are being used as checks against the anthropometric technique. The technique of cross sections of the hair of twins will be added to the battery of tests already mentioned.

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NUTRITION LABORATORY

Boston, Massachusetts

THORNE M. CARPENTER, *Acting Director*

The research program of the Nutrition Laboratory has been continued along the lines of investigation that were discussed in the introduction to last year's report. These investigations deal with the heat regulation of men and animals, the basal or minimum heat production, and the changes in the combustion of nutrients as shown by measurement of the respiratory quotient. The respiratory quotient is the ratio between the volume of carbon dioxide eliminated and the volume of oxygen absorbed during the change of one kind of nutrient to another, such as the conversion of carbohydrates into fat, or during the complete combustion of varying mixtures of foodstuffs or body tissues. During the past year certain objectives in the above program have been completed, and progress has been made in others.

In the field of heat regulation, the rectal temperature of the normal adult wild cotton-tail rabbit has been measured and its limits have been determined. The average rectal temperature was not far from that of domestic rabbits previously studied in the Laboratory. The minimum heat production (basal metabolism) of these same wild rabbits has been measured under standard conditions and at thermic neutrality (the temperature at which the heat production is the lowest) and has been found to be 6 per cent higher than that of the domesticated varieties. We thus have a comparison of the wild and domestic types of this species in two important aspects of normal physiology. With domestic rabbits simultaneous measurements of the heat production and the continuous loss of weight, the so-called insensible perspiration (which takes place in all animals, in general), have shown that there is a relation between these two factors but that the determination of the insensible perspiration cannot be substituted for the direct determination of the heat production.

The study of the rates of combustion of simple sugars (glucose, fructose, and galactose) in cats has been continued in order to compare the findings on a representative of the Carnivora or meat-eating animals with those on other species investigated in previous years.

The investigation on the rapidity and the amount of combustion of carbohydrates (sugars and starches) by human subjects has been completed with a certain number of foods. In general, those foods that had the greatest content of simple sugars (like glucose) and hydrolyzable sugars (like cane sugar) resulted, when ingested, in the most rapid and largest combustion of carbohydrates, whereas starchy foods (rice, potatoes) produced a slower and longer-continued increase in combustion of carbohydrates.

The cooperative investigation on the utilization of carbohydrates by patients with diabetes mellitus, particularly those resistant to insulin (the hormone used to treat diabetes), has raised a number of questions to be answered by studies on normal individuals. It is a common practice to introduce glucose into the body by intravenous injection, particularly in surgical emergencies. When this was tried with diabetic patients, there was frequently no indication of the utilization of glucose by these individuals. This finding led to a systematic comparison, with four normal young men, of the combustion of glucose when introduced by mouth and by vein. In this study the respiratory exchange was measured for a definite period after the glucose solution was administered, as a basis for the calculation of the amount of glucose burned. The results showed little, if any, difference between the two methods of feeding in the amounts of glucose burned. Another problem that arose was whether the amount of glucose burned would vary according to the store of

carbohydrates in the body, when a definite amount of glucose was given, and whether this store could be altered by diets containing definite quantities of carbohydrates. The carbohydrate stores in diabetic patients vary widely, much more so than in normal, healthy persons. A systematic study has therefore been made with two normal young men, to

gain information on these questions. Both of these special investigations with normal individuals, which arose from the study of diabetic patients, constitute investigations in pure as well as applied science, for even without application to the diabetic problem they are contributions to the normal physiology of man.

STAFF NOTES

Robert C. Lee was elected a member of the American Institute of Nutrition in March 1940. On June 4 he gave a lecture to members of Boy Scout Troop 11 of Dorchester, Massachusetts, on "The development of a scientific instrument," and demonstrated an apparatus for the rapid measurement of body temperature by measurement of the maximum temperature of the expired air.

In November 1939 Dr. T. M. Carpenter served as a member of the Committee on Awards of the Herman Frasch Foundation; in January 1940 he became an associate editor of a new journal called *A Quarterly Journal of Studies on Alcohol*; and on March 13, 1940 he was elected President of the American Institute of Nutrition for the year 1940-1941. On December 12, 1939 Dr. Carpenter talked to the Boylston Chemical Club of Harvard University on "The chemistry of alcohol in man." At the New Orleans meeting of the American Institute of Nutrition, on March

13, 1940, he gave a paper entitled "Carbohydrate combustion in man after oral versus intravenous administration of dextrose," in cooperation with Dr. H. F. Root, of the New England Deaconess Hospital. At the meeting of the American Physiological Society in New Orleans, on March 15, he gave a paper entitled "The effects of hexoses on respiratory quotients (R. Q.) of goats," in cooperation with Professor E. G. Ritzman, of the University of New Hampshire. His annual lecture on basal metabolism to the first-year class at the Harvard Medical School occurred on March 22.

Groups of students from Regis College in Weston, Massachusetts, from the Harvard Medical School, and from Wellesley College visited the Laboratory during the year, to see the various types of apparatus in use here and to become acquainted with the general nature of the investigations.

INVESTIGATIONS IN PROGRESS

Respiratory failure of newborn infants. The incubator employing mixtures of helium and oxygen to combat respiratory failure of newborn infants of diabetic mothers, constructed in cooperation with Dr. Priscilla White, of the New England Deaconess Hospital, has been described and an account published of the experience with the apparatus. (See page 236.) The equipment has been maintained at the Faulkner Hospital in Boston for emergency use.

Insensible loss of weight and metabolism of the rabbit. This study, made to determine whether there is a relation between the in-

sensible loss of weight and the metabolism of the rabbit, the factors affecting such a relation, and the possible use of the insensible loss of weight as an index of basal metabolism, has been carried to completion, and a report of the findings is in press. (See page 237.)

Habituation of the rabbit to various environmental temperatures and its effect on the basal metabolism. Further work on this problem has been carried out to contribute information on the more subtle factors causing variations in the basal metabolism.

Relation of body composition to basal

metabolism. Rabbits that were used for basal metabolism studies are being dissected and analyzed to establish whether there are any relations between the size of the organs, the body composition, and the basal metabolism. G. Lee has assisted R. C. Lee in all these investigations on rabbits.

Electrical method of gas analysis. The apparatus like that devised by Professor A. K. Noyons, of the University of Utrecht, Holland, constructed and completed last year by V. Coropatchinsky, has had certain modifications made in it so that the results obtained for oxygen content of gaseous mixtures are much more reliable and uniform than were obtained at first. The apparatus promises usefulness in determining the composition of gaseous mixtures in which there are no foreign gases other than those found in ordinary atmospheric air. In view of conditions during the past few months in Europe, it may well be that this is one of the few apparatus of this type in intact condition.

Effect of ingestion of hexoses on the respiratory quotient of the cat. The study on the effect of ingestion of hexoses on the respiratory quotient of the cat has been continued at intervals throughout the year. Investigations have been made with four cats with respect to the influence of glucose, fructose, and galactose and with respect to ingestion of varying quantities of these sugars. These cats, now having been standardized, have also been used for the testing of the possible utilization of unusual sugars, samples of which have been furnished us by Dr. H. A. Spoehr, of the Division of Plant Biology. The observations have been made by B. James.

Basal metabolism of the rabbit in experimentally produced atherosclerosis. Study of experimentally produced atherosclerosis in adult rabbits, begun two years ago, has been continued in cooperation with Dr. Timothy Leary, Medical Examiner of Suffolk County, Massachusetts. The metabolism studies of the rabbit are being carried on by G. Lee under the supervision of R. C. Lee.

Analysis of foods and combustion of carbohydrates. The study on the effect of ingestion

of foods and their combustion with respect to carbohydrates has been completed during the past year and has formed the basis for an exhibit at the annual exhibition of the Carnegie Institution of Washington. The material has been brought to completion and the results have been published. (See page 237.)

Metabolism in diabetes mellitus. The observations on the respiratory exchange of diabetic patients, begun last year, have been continued at the Baker Clinic of the New England Deaconess Hospital. Particular attention has been given to patients having a high resistance to insulin and to patients with acromegaly. Problems arising in connection with these studies have necessitated the carrying on of auxiliary studies on normal subjects. The investigation is being carried on with the cooperation of Dr. H. F. Root, and the respiratory exchange measurements are being made by B. James.

Combustion of carbohydrates after intravenous versus oral introduction in humans. In connection with the studies of metabolism in diabetes it has been found not infrequently that when sugars were introduced intravenously, there was no indication of combustion of the carbohydrates. As intravenous injection is a routine procedure in hospitals in general, particularly with surgical patients, it seemed desirable to obtain information as to what the normal individual would do with sugars introduced in this manner. A systematic study on four normal students was carried out, in which comparison was made of the respiratory exchange as affected by oral or intravenous administration of 50 grams of glucose in suitable solutions. A preliminary report has been made on this work. (See page 238.) The study was carried on with the cooperation of Dr. H. F. Root, of the Baker Clinic, New England Deaconess Hospital, and the measurements were made by B. James.

The effect on the respiratory quotient of ingestion of glucose at different levels of carbohydrate intake in humans. To aid in the interpretation of the findings in the investigation on diabetes mellitus, a study has

been made on the relation between the carbohydrate intake (high, low, or carbohydrate-free) per day and the level of the respiratory quotient, and on the effect of the ingestion of 50 grams of glucose on the respiratory quotient at the different levels. Observations on two normal students were carried on for

over two weeks. The study was made with the cooperation of Dr. H. F. Root and with the assistance of Miss R. Vance, dietitian of the Baker Clinic, New England Deaconess Hospital. The respiratory exchange measurements were made by B. James, with the assistance of G. Lee as gas analyst.

LITERARY WORK

Steps have been taken by Dr. Carpenter for the preparation of a review of the literature on energy metabolism published during the year ending September 1940, which will appear in the *Annual Review of Physiology*, volume 3 (1941).

A report is in preparation by R. C. Lee on

skin temperature measurements of a pig, a goat, a sheep, and a ram, made at the University of New Hampshire in cooperation with Professor E. G. Ritzman and N. F. Colovos.

The preparation of publications and the editorial work have had the efficient supervision of the editor, Elsie A. Wilson.

PUBLICATIONS

- (1) *An infant incubator employing controlled mixtures of helium and oxygen to combat respiratory failure.* Francis G. Benedict, Priscilla White, and Robert C. Lee. Amer. Jour. Obstet. and Gynecol., vol. 39, pp. 63-70 (1940).

Not only can the temperature, humidity, and ventilation of this incubator be controlled, but also the composition of the atmosphere within it. The incubator was designed to facilitate respiration by providing an atmosphere containing a known mixture of oxygen and helium. When necessary, a mixture of carbon dioxide and oxygen can be used as a respiratory stimulant. The composition of the gaseous mixture inside the incubator is determined and the constancy of this composition is demonstrated by means of a densimeter. The incubator proved helpful in several instances in preventing asphyxia of newborn infants of diabetic mothers, but subsequently it was found that the respiratory failure of such infants can be successfully prevented by prenatal hormone therapy. The clinical experience with the incubator is reported.

- (2) *Basal metabolism of the adult rabbit and prerequisites for its measurement.* Robert C. Lee. Jour. Nutrition, vol. 18, pp. 473-488 (1939).

The prerequisites for basal metabolism measurements of adult rabbits are a good nutritive state, a rectal temperature between 38.4° and 41.1° C., muscular repose, fasting for 24 to 72

hours prior to measurement, and habituation to environmental temperatures of 28° to 32° C. (thermic neutrality) for at least 24 hours beforehand and earlier than this to temperatures between 20° and 32° C. Time of day is immaterial. The initial experiment on any rabbit not previously accustomed to laboratory procedures should be considered only an orientation experiment. There was no pronounced correlation between rectal temperature and heat production. The basal total heat production of 74 adult rabbits (1 to 7 kg. in weight) ranged in 251 experiments from 60 to 335 calories per 24 hours, and the basal heat production per square meter of surface area ($0.001w^{2/3}$) from 534 to 914 calories, being in general greater the heavier the rabbit. The values per unit of surface area were lower than most of the values reported in the literature. The males tended to have a slightly higher metabolism than the females.

- (3) *Size and basal metabolism of the adult rabbit.* Robert C. Lee. Jour. Nutrition, vol. 18, pp. 489-500 (1939).

With adult rabbits having a sevenfold range in weight, no method is known for equalizing differences in size so that one value will accurately express the average basal metabolism of all rabbits. Simple linear relations between basal metabolism and size are found when the heat production is expressed per square meter of surface area and per W^n for values of n

between 0.61 and 0.73 inclusive, but the relation between the basal metabolism and the size of the adult rabbit is best expressed by referring the total heat production to the weight. The basal total heat production increases at a constant rate for each kilogram increase in weight between 1 and 7 kg., and can be predicted by the equation $h_{\text{total}} = 40W + 20$, in which h_{total} represents kilogram-calories per 24 hours, and W , the weight in kilograms. The rabbit's basal total heat production is slightly below the average total heat production of other warm-blooded animals of like weight, except the marmot. Its average basal heat production per square meter of surface area agrees with the general average for other warm-blooded animals at 5 kg., but is below the general average at the lower weights.

- (4) *The rectal temperature and the metabolism of the wild cottontail rabbit.* Robert C. Lee. Jour. Nutrition, vol. 19, pp. 173-177 (1940).

The rectal temperatures of 8 wild cottontail rabbits, adult and weighing on the average 0.98 kg., increased as the depth in the rectum at which the measurement was made increased. The average difference in temperature at the 75- and the 150-mm. depths was 0.3° C. (environmental temperature, 28° C.). At 150 mm. the rectal temperature averaged 39.9° C. Twenty-four hours of fasting at environmental temperatures between 10° and 28° did not lower the rectal temperature. Air temperatures between 16° and 28° had no effect, but those of 10° to 12° C. lowered the rectal temperature 0.7° C. Exercise for 3 to 4 minutes increased the body temperature 0.3° to 2.1° C. The basal total heat production averaged 64.9 calories per 24 hours and the heat production per square meter of surface area ($0.001w^{2/3}$), 652 calories. At 16° C. the metabolism was 49 per cent above the basal level. The wild cottontail rabbit has a basal metabolism 6 per cent higher than the domestic rabbit of the same weight.

- (5) *Relationship between insensible loss of weight and heat production of the rabbit.* Robert C. Lee. Jour. Nutrition, vol. 20, pp. 297-304 (1940).

With 12 adult rabbits at 28° to 29° C., after a fast of 24 hours at 28° C., simultaneous measurements of the insensible loss of weight and the heat production demonstrated that there was a relation between these two factors. This relation was not affected by changes in relative humidity between 40 and 80 per cent or by

changes in the level of normal body temperature, but was altered slightly when the rabbits were fed. Within the range of 1.5 to 5.0 grams of insensible loss per hour, the relation can be expressed by the equation $H = 1.45L + 2.32$, in which H equals kilogram-calories per hour, and L , grams of insensible loss per hour. The percentage differences of the measured heat production from the heat production calculated from this equation have a standard deviation of ± 8.9 per cent. Measurements of the rabbit's insensible loss of weight will enable approximate calculation of the probable heat production prevailing at the time of measurement but will not replace exact measurements of the respiratory exchange. The amount of heat lost by vaporization of water (calculated indirectly) averaged 24.6 per cent of the measured heat production.

- (6) *Composition of some common foods with respect to the carbohydrate content.* Thorne M. Carpenter. Jour. Nutrition, vol. 19, pp. 415-422 (1940).

Twenty kinds of common food, including rice, macaroni, bread, six kinds of vegetables (both raw and cooked), six kinds of nuts, dates, and figs, were analyzed with reference to their content of reducing sugars, hydrolyzable sugars, starch, cellulose, water, protein, fat, and ash. Their heats of combustion were also determined. Comparisons are made with previous analyses of like foods by other investigators.

- (7) *The combustion of carbohydrates in man after ingestion of common foods.* Thorne M. Carpenter. Jour. Nutrition, vol. 19, pp. 423-435 (1940).

The respiratory exchange and the urinary nitrogen elimination of a man were measured before and after he had eaten a portion of some common food containing approximately 25 grams of available carbohydrates. From these measurements the carbohydrate combustion before and in twelve successive 15-minute periods after food ingestion was calculated. The increase in carbohydrate combustion in the three hours following food intake was greater, the greater the content of reducing and hydrolyzable sugars in the food, and smaller, the greater the starch or fat content. Boiled parsnips, beets, carrots, and squash caused the greatest increases and nuts, rice, macaroni, white potato, and bread the smallest increases. Raw carrots caused a greater combustion of carbo-

hydrates than cooked carrots, but the result was the opposite with white potatoes. Cane sugar and dates caused a sudden and marked increase in carbohydrate combustion, but this increase did not last long. The increase after glucose was more gradual and less pronounced but lasted longer. In the case of parsnips the readily digestible carbohydrates were burned first, and subsequently the more complex carbohydrates became available. The increases were small but continuous with nuts and somewhat greater with cashew than with other nuts.

- (8) *The effects of hexoses on respiratory quotients (R. Q.) of goats.* Thorne M. Carpenter and Ernest G. Ritzman. Amer. Jour. Physiol., vol. 129, pp. 329-330 (1940).

Abstract. (See page 234.)

- (9) *Carbohydrate combustion in man after oral versus intravenous administration of dextrose.* Thorne M. Carpenter and Howard F. Root. Jour. Nutrition, vol. 19, supp. p. 10 (1940).

Abstract. (See page 234.)

- (10) *The Theodore William Richards Medal.* Thorne M. Carpenter. The Nucleus, vol. 17, pp. 205-207 (1940).

Remarks made at the presentation of the Theodore William Richards medal to Professor Claude Silbert Hudson, of the National Insti-

tute of Health, on behalf of the Northeastern Section of the American Chemical Society.

- (11) *The metabolism of alcohol. A review.* Thorne M. Carpenter. Quart. Jour. Studies on Alcohol, vol. 1, pp. 201-226 (1940).

This review of the literature deals with the methods of study of the metabolism of alcohol, the amount of alcohol normally in the body with no alcohol intake, the absorption of alcohol in the alimentary tract, by rectum, after injection into the urinary bladder, and by inhalation through the lungs, the distribution of alcohol in the body after absorption, and its elimination by various paths, such as urine, sweat, and expired air. Consideration is given to the effect of size and concentration of dose on the concentration of alcohol in the blood, the effect of habituation or tolerance on the metabolism of alcohol, and the effect of alcohol concentration in the body on the rate of disappearance of alcohol from the body. The rates of oxidation of alcohol by different animals are compared and respiratory exchange studies are cited in which the respiratory quotient served as a proof of the oxidation of alcohol. The replacement of foodstuffs by alcohol is touched upon. Finally, the effects on alcohol metabolism are reported of such factors as food ingestion, muscular work, drugs (dinitrophenol, caffeine, atropine, morphine, and urethane), and hormones (insulin, thyroxine, adrenaline, and pituitrin). A list of the 166 references upon which the review is based is appended.

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— See BENEDICT, FRANCIS G.
RITZMAN, ERNEST G. See CARPENTER, THORNE M.
ROOT, HOWARD F. See CARPENTER, THORNE M.
WHITE, PRISCILLA. See BENEDICT, FRANCIS G.

SPECIAL PROJECTS: BIOLOGICAL SCIENCES

KATHERINE S. BREHME, Department of Genetics, Cold Spring Harbor, Long Island, New York. *Preparation of a reference book on the mutants in Drosophila melanogaster.*

The reference book on the mutants of *Drosophila melanogaster* planned and begun by Dr. C. B. Bridges was in first draft at the time of his death in December 1938. He had planned to describe each point mutation or chromosomal aberration known in *melanogaster*, including such genetical, cytological, and other information as would be necessary or useful to the research worker using these mutations or to the reader seeking to interpret the literature. It was his intention to communicate with each of the investigators who originally described the mutants, asking for confirmation of the descriptions and for additional information. He expected also to make a careful survey of the literature in order to verify the descriptions and to add full bibliographic references.

The first draft was issued in November 1938 as *Drosophila Information Service* 9, and contained descriptions of the mutants, with incomplete bibliographic references and for the most part unconfirmed by other investigators. There had not been time for Dr. Bridges to cover in detail more than a few references.

The work of completing Dr. Bridges' book has proceeded as follows, in collaboration with Dr. M. Demerec. In September and October 1939, letters were sent to each of the investigators who had found or worked extensively with the individual mutants; each was asked for confirmation of the descriptions in DIS-9, for information about new mutants, and for descriptions of the wild-type stocks now in use. Virtually all the

American investigators have replied to this request, and the majority of those in Europe and Asia; the replies have been incorporated in the text of the book. Periodicals and other literature containing reports of research on *Drosophila melanogaster* have been carefully studied, and additions and corrections made to the descriptions and bibliography; this survey of the literature is almost complete. From the literature and the reports of investigators, over 100 mutants have been added to those included in DIS-9. A list has been compiled of all available illustrations, both published and unpublished (with the cooperation of Miss E. M. Wallace), and engraver's copy is now being made.

Within the next several months, it should be possible to prepare the manuscript in its final form.

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PHILIP N. BRIDGES, Columbia University, New York, New York. *Revision of salivary-gland chromosome maps of Drosophila melanogaster.*

The revision of the 2R salivary chromosome map, which was started in collaboration with C. B. Bridges (as noted in Year Book No. 37 [1937-1938], report of T. H. Morgan, C. B. Bridges, and Jack Schultz) and left

uncompleted at his death, was finished during the summer of 1939 by Philip N. Bridges.

The material which had been collected for this revision was subjected to a thorough checking to put it in shape for publication,

and a composite map was made from the material, which consists of drawings of the right limb of the second chromosome. These drawings, seven or eight for each of the twenty sections of the chromosome limb, had been done by the two authors in the summer of 1938, from specially selected permanent preparations.

The completed revision represents all lines of the chromosome with better relative intensities, spacing, and characteristics than did the map of 1935 (C. B. Bridges, *Journal of Heredity*, vol. 26). Comparison of the earlier map with the present revision shows an increase in number of lines from 660 to 1136 (Bridges estimated 960 in the report cited above), and increase in length from 245 microns to 446 microns.

Starting in September of 1939, revision of the remaining salivary-gland chromosomes, namely 3L, 3R, and 2L, was initiated, the whole series of revisions being kept uniform with C. B. Bridges' X-chromosome revision (*Journal of Heredity*, vol. 29, 1938), that is, reproduced at a magnification of 3100 diameters,

BARBARA S. BURKS, Genetics Record Office, Cold Spring Harbor, Long Island, New York.
Research projects in the field of human heredity. (For previous reports see Year Books Nos. 36-38.)

The following report has been submitted with relation to studies undertaken at the Genetics Record Office by Dr. Burks with support of funds granted by the Carnegie Corporation of New York to the Carnegie Institution of Washington.

Studies designed to clarify the transmission mechanism of single traits were continued with the assistance of Frances Carlson, Frances W. Burks (summer 1939), Maria Rosler and Barbara S. Bosanquet (winter 1939-1940), and Marianne Bernstein (summer 1940). Hair color, distribution of mid-digital hair, shade of iris rim, finger curvature, and relative length of central and lateral upper incisors have all been scrutinized. The data utilized were collected as "linkage test" material in connection with earlier field studies on tooth deficiency and on myopia (see Year Book No. 37), with the exception

of those on incisors, which were gathered in 1939 and 1940 through the cooperation of Huntington High School and the Guggenheim Dental Clinic.

During the year revision of the 3L salivary-gland chromosome map was completed (to be published in *Journal of Heredity*, 1940). Comparison of the 1935 map with this map gives an increase in the number of bands from 542 to 884, and an increase in length from 210 to 424 microns. A new technique in drawing has improved somewhat the reproduction of the relative intensities of the bands as compared with that in the other revisions published.

At the end of the period covered by this report the revision of the 3R salivary chromosome map was about half completed, and it is estimated that there will be approximately 1200 bands and a length of 480 microns in this revision, as compared with 697 lines and 280 microns length in the old map.

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of those on incisors, which were gathered in 1939 and 1940 through the cooperation of Huntington High School and the Guggenheim Dental Clinic.

Though final reports upon these studies are not yet prepared, it may be tentatively stated that melanic hair color, in different ethnic groups, appears to be due sometimes to a single gene pair showing dominance and sometimes to cumulative nondominant allelomorphs. Distribution of mid-digital hair (i.e., hair over the middle phalanges of the fingers) appears to be governed by a series of alleles ranging from weak to strong, rather than by a "presence and absence" pair with modifiers. Shade of iris rim and finger curvature have not yielded to any simple Mendelian system. "Long" and "short" lateral incisors are probably due to a single gene pair showing dominance, but the developmental data obtained

from Guggenheim Clinic on preadolescent children indicate that the trait is not readily diagnosed until stability of jaw structure has been attained.

The importance of obtaining numerous normal "test factors" for use in linkage studies justifies expenditure of considerable time on studies of the kind described above. The search for linkage systems in man need not wait, however, upon the laborious building up of a catalogue of test factors, since we already have enough normal human traits to warrant linkage tests in any pedigree study undertaken to establish the mode of transmission of rare or atypical traits. A demonstration of this procedure was made possible during the current year when Miss Helen Wyandt, of the University of Nebraska Medical School, requested cooperation in an investigation of the inheritance of oval red blood cells. Miss Wyandt carried out field work in Nebraska and abroad in consultation with the Genetics Record Office. The results were worked up collaboratively, and were examined with respect to evidence for "non-linkage" as well as for linkage, since it appears that many studies in the past have discarded results that gave no statistically reliable evidence for linkage, without inquiring whether the data would be adequate to establish linkage if present. When oval cells were tested against hair color, mid-digital hair, sex (i.e., incomplete sex linkage), capacity to taste phenyl-thio-carbamide, and the A-B blood agglutinogens, the relation between oval cells and the A-B groups was marked enough to indicate the desirability of further investigation. Close linkage of oval cells with hair color and sex seemed to be ruled out; the results with the remaining traits were equivocal.

Data from the Genetics Record Archives continue to yield suggestive results. Through the use of families selected according to the socioeconomic status of parents and grandparents, it has been possible to study (1) the contribution of grandparental status over and above that of parental status to the prediction of status of offspring and (2) the relation of high and low socioeconomic status and of

stable and rising socioeconomic status to family size. Findings from the latter study confirm R. A. Fisher's hypothesis that diminished fecundity accompanies social promotion, but fail to confirm Fisher by showing the fecundity of the "socially established" to be lower than that of the "socially promoted." A further study designed to check upon the social promotion hypothesis was undertaken during the year by Mrs. Bosanquet, utilizing data available in *Who's who in America*. The results are not yet ready to report upon.

In the spring of 1940, a grant was made available by the Carnegie Corporation for undertaking a new investigation of foster children. The work is to be done in close cooperation with the State Charities Aid Association of New York, with Dr. Burks as director of the study. As the work on this study will be centralized in New York City, the Social Science Research Council has been requested, and has kindly agreed, to sponsor it. A committee of the Social Science Research Council is serving in an advisory capacity. Dr. Gladys C. Schwesinger has been collaborating as research assistant. Up to the present, surveys of available cases for study and of relevant scientific literature have been made, and plans have been laid for appraising the foster-care outcomes in subjects selected as having had true parents who deviated widely from normal mentality or behavior (i.e., aments, psychotics, alcoholics, etc.). It is clear that the foster-child approach offers the possibility of obtaining crucial answers to problems of development and organic plasticity not ordinarily accessible in studies of offspring growing up in their own homes, where hereditary and environmental factors are inseparably related. This new study has not supplanted other investigations, but the director has devoted to it approximately one-quarter time.

Related in purpose and general approach, though a continuation of a study undertaken some years ago, has been a follow-up of a pair of monozygotic twins reared separately, and in very different family and school environments. Such studies, even more than studies of ordinary foster children, may be

expected to yield crucial data on the possibilities and limitations of training. The present study (which is still in progress) shows evidence that (1) under environmental pressures, even when these are qualitatively quite different, similar problems may develop in similar organisms (e.g., enuresis, nail-biting); (2) group intelligence tests are more sensitive to schooling differences than are individually administered intelligence tests, but the twin difference on group tests may be assimilated after schooling is equalized; (3) interest patterns, of the kind contributing to vocational success, become more alike with age even though experiences continue to be different, which may mean that with the accumulation of diverse experiences, an individual is better able to select and incorporate those most congruent with his organic potentialities.

A limited amount of time has been given to the preparation of reviews of scientific

literature when such undertaking seemed likely to enrich the necessary background for research projects in progress at the Genetics Record Office.

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PAUL S. CONGER, Washington, District of Columbia. *Investigations and preparation for publication of results of studies on Diatomaceae*. (For previous reports see Year Books Nos. 18-38.)

During a sojourn of ten weeks at the Tortugas Laboratory a detailed study was made of the life history, morphology, and reproduction of two species of *Amphora* which are new and unusual in these respects and which form an important part of the diatom population of the region. Investigations of diatom locomotion were continued, which led to a new conception of the method of this movement and its importance. Further studies were also made of the silica relations of diatoms in these waters where the amount of dissolved silica is exceptionally meager and is consequently of critical importance to the plankton diatom population. It is considered particularly fortunate to have had opportunity to compare the diatom plankton of these chemically poor waters with that of other regions where growth is more profuse. The plankton which plays such an important role in the economy of the sea is here unique and relatively unstudied, and affords unusual opportunity for studies which throw light on these problems.

Following the above work, a month spent at the Trout Lake Limnological Laboratory in northern Wisconsin in cooperation with the University of Wisconsin was devoted chiefly to obtaining vertical cores of lake bottoms and to the study of concentrated diatomaceous sediments. With a new type of sampler it was possible to obtain samples at accurate intervals of every half-foot or foot, down to a depth of 16 feet in the bottom sediments. The sediments are very soft and flocculent, and these samples should give us a better picture of the course of diatom deposition than has been possible heretofore. Several new diatomaceous peat deposits of high diatom concentration were located, one in a lake of approximately 150 acres with a sediment probably ranging between 10 and 20 feet in thickness lying under only 3 feet of water. This consisted mainly of large *Cymbella* forms productive of a light, porous earth, promising to be of commercial interest. Examination of such deposits gave further information as to their formation, and the

importance, in this process, of cold seepage waters in lakes of slightly hard water became increasingly apparent.

An exhibit was prepared as a part of the annual exhibition of the Carnegie Institution in December illustrating "The formation of diatomaceous peat deposits." A profile of a lake basin showed the original basin, the diatomaceous peat deposit, the water body, and the shore area, using the actual sand and peat materials, and giving an accurate picture of the place and extent of deposition. Also included in the exhibit were samples of different types of lake sediment—marl, organic peat, and diatomaceous peat—together with other bottles showing the diatomaceous peat in different stages of refinement. A series of wall photographs showed the steps in recovery of diatomaceous sediment from a lake or bog and its processing to produce an industrial earth. A wall map of the concentrated lake district of northern Wisconsin illustrated the potentialities for diatomaceous deposition if even a very small percentage of the lakes are productive of good diatomaceous material. The high purity of such sediments and the great diversity in the sediments of several different lakes within a small area were illustrated by slides under a number of microscopes. Attention has been focused upon the ecological factors which control the growth of different kinds of diatom to produce such diverse materials in closely similar lakes in a small area, as these represent the principles which govern the production of such useful materials. Information thus gained is in turn being applied as a basis for the interpretation of deposits formed in the geologic past.

A study was made of several samples of material collected by Dr. L. S. Cressman and Dr. Edgar Howard in the Klamath Lake basin in Oregon in connection with archaeological studies under the direction of Dr. John C. Merriam. The samples showed an earlier, more primitive diatom deposit at a high elevation and a recent deposit at a lower level in the subsequently eroded Klamath river basin. The latter materials indicated a deposit of good commercial value in the

present lake basin. As the lake is soon to be dammed, this deposit will doubtless be covered with other sediments.

Other studies included the examination of material from oyster-shell mounds on an island in the Tennessee River for the University of Alabama. No diatoms were found in this material, but it would seem probable that they had been present at one time and perhaps washed away.

Examinations were also made of material from diatom deposits in New Zealand of interest to the government of that country, and brought in interesting new materials. Other accessions to the collection included extensive materials from Maryland and Virginia, the latter in connection with borings for the location of such deposits, by a commercial concern.

A preliminary examination of diatom collections of the Second Byrd Antarctic Expedition showed a few diverse samples, but the majority were mainly of typical Antarctic plankton. Promise has been received of additional material from the present expedition.

Investigations of Maryland and Chesapeake Bay diatoms were continued during the year, and plans were made for summer investigation, and for again offering a course on diatoms at the Chesapeake Biological Laboratory in the summer of 1940.

A seemingly useful new application of diatomaceous earth resulted from the suggestion, in connection with a case of abnormal arrangements of the tubes discharging the bladder in which an operation made necessary continuous artificial drainage, creating troublesome sanitary problems, that diatomaceous earth be used as an absorbent. This pure, inert, harmless material in powder form has an absorptive power equal to approximately nine-tenths of its gross volume, and has the advantage of having a practically dry and plastic feeling until it reaches a state of complete saturation, when it can easily be renewed. This proved a better and more comfortable method than those previously employed. The desirability is suggested of a more general examination of the usefulness

of this material as an absorbent in case of operations involving artificial drainage.

An ever increasing number of requests for information regarding diatoms, and for examination of samples of diatom material, was answered during the year.

A general exhibit of Maryland diatoms was

put on at the annual Maryland Biology Teachers Convention, held at St. John's College in Annapolis, in April.

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TH. DOBZHANSKY, Columbia University, New York, New York. *Studies on the genetic structure of natural populations*. (For previous reports see Year Books Nos. 37, 38.)

Continuation of these studies has been possible by reason of a grant from the Carnegie Corporation of New York to the Carnegie Institution of Washington.

Experiments made in 1937 have shown that populations of the small fly *Drosophila pseudoobscura* inhabiting the mountain ranges of the Death Valley region in California and Nevada differ from each other in the incidence of certain chromosome structures and mutant genes. The mountain ranges in question being separated by intervening stretches of desert only a dozen or so miles wide, the occurrence of differences between the populations was unexpected. The following year (1938) Dr. P. Ch. Koller found that populations from localities only a few miles apart on the same mountain range show differences of the same order of magnitude as do samples from different ranges. Similar differences have been detected also between populations from adjacent localities in Texas (samples furnished by Professor J. T. Patterson). Since there were no obvious impediments to the migration of the flies between the localities in which Koller's and Patterson's collecting was done, it became clear that the species *Drosophila pseudoobscura* is subdivided into extremely local races which seem to undergo evolutionary changes independently of each other. Similar situations have been known for some time in certain land snails, but so fine a subdivision appeared surprising in a species possessing as good means of locomotion as *Drosophila* does. Since the problem of race formation is basic for an understanding of the process of evolution, and since *Drosophila* has unusual advantages as material for such studies, it

has been decided to subject the phenomenon of local differentiation in *Drosophila pseudoobscura* to as close a scrutiny as the means available permit.

Nine collecting stations were chosen on Mount San Jacinto, California. Each "station" is an area of at most 100 yards square, in which fifteen traps for collecting the flies are exposed on previously marked trees. The nine stations are grouped in three "localities." The distances between the stations within a locality vary from about $\frac{1}{4}$ mile to 2 miles; the distances between the localities are from 10 to 15 miles. The whole territory is covered with forest and brush vegetation, offering no obstacles to migration of the flies. Starting in March and April of 1939, samples of the population of *Drosophila pseudoobscura* were collected during the breeding season at all stations at intervals of 4 to 5 weeks. The flies were taken alive to the laboratory, where the frequencies of the various gene arrangements in the third chromosomes were determined, and some of the samples were examined for recessive third-chromosome lethals. In addition, yearly collecting was done in the Panamint Range, Death Valley region, for which data are available for 1937 and succeeding years. Professor Patterson has kindly continued to supply samples from a locality near Austin, Texas.

The observations being still in progress and the analysis of the data far from complete, only tentative conclusions can be reported at present. Perhaps the most interesting, and also the best established, among them is that the genetic constitution of the population at a station varies not only from year to year but even from month to month. As an illustra-

tion, an excerpt from the data is given in table 1, showing the percentage frequencies of the five gene arrangements encountered in samples from the station Piñon A.

It is obvious that during the period of observation the genetic composition of the population underwent statistically significant changes. These changes are not entirely haphazard, in the sense that two consecutive collections are more likely to give similar results than collections far apart in time. Nor are the changes definitely directed, since a trend in the frequency of a given arrangement may be reversed in sign. It is notable

a differentiation does or does not occur between localities within a geographic region. As far as the available data go, such a differentiation appears to exist, although the amplitude of the temporal fluctuations is sometimes great enough to eclipse the interlocality differences. Moreover, the differences between localities are geographically irregular; for example, the populations of adjacent ranges in the Death Valley region appear no more likely to be similar than those from remote ranges. The situation changes, however, if populations from localities a hundred or more miles apart are compared (such

TABLE I

DATE OF COLLECTING	GENE ARRANGEMENT					CHROMOSOMES EXAMINED
	Standard	Arrowhead	Chiricahua	Tree line	Santa Cruz	
April 24, 1939.....	48.7	33.3	15.4	2.6	.....	39
May 13-14.....	30.8	35.8	27.5	3.3	2.5	120
June 21-22.....	32.8	37.1	26.7	2.6	0.9	116
August 19-20.....	34.7	33.3	23.6	8.3	.....	72
September 19-20.....	49.0	21.0	24.0	4.0	2.0	100
October 21-22.....	56.0	24.6	13.6	5.0	0.7	134
March 3, 1940.....	49.0	16.0	29.0	6.0	.....	100
March 28-29.....	39.5	24.6	30.7	3.5	1.7	114
April 21.....	34.9	18.6	41.9	3.5	1.2	86
May 10.....	31.4	31.4	35.3	2.0	.....	102
June 1-2.....	29.4	29.4	39.7	1.5	.....	68

that the trends, while they last, are usually similar at all stations within a locality, although exceptions to this rule apparently occur. Although this cannot be considered established, the trends in different localities appear to be independent. The changes do not go on all the time. For example, the population of one of the localities apparently remained static during the season of 1939, while other localities were in the process of change.

The populations inhabiting stations within a locality may be distinct in composition at any given time, but the differences involved are only as great as or smaller than the fluctuations with time within the stations. In other words, there is no permanent racial differentiation between stations within a locality. It is too early to decide whether such

"localities" may be said to represent different "regions"). Here geographic gradients, or clines, become apparent. Table 2 is an example of the data bearing on this point.

The localities in table 2 are arranged roughly from west to east. In contrast with the haphazard character of local variation, the major geographic subdivisions of the species display definite regularities. The frequencies of the standard and Chiricahua arrangements diminish as one moves eastward; that of Pikes Peak decreases westward; that of the Arrowhead arrangement reaches a maximum in Arizona and the adjacent part of Colorado and wanes in either direction therefrom.

The evidence discussed above concerns exclusively the variations in the gene arrangement in the third chromosome of *Drosophila*

pseudoobscura. Independent evidence bearing on the same problems may be obtained by examining the recessive lethals which are known to be abundantly represented in natural populations (see the reports in Year Books Nos. 37, 38). Since in a large undivided species the frequencies of lethals at all loci are simply functions of the mutation rates of the latter, the frequency of alleles among the lethals found in natural populations must be independent of the source of these lethals, whether from the population of the same or of different localities. If, on the other hand, local populations are genetically

Statistically valid differences between populations inhabiting stations within a locality are, thus, established. Populations of localities within a region differ more extensively than do populations of stations within a locality. As far as the data go, there seem to be no significantly greater differences between populations of different regions than between populations of different localities within a region. The temporal fluctuations in the composition of the local populations, which are so strikingly apparent in the data involving gene arrangements, are less pronounced in the data on lethals; nevertheless, alleles seem

TABLE 2

LOCALITY	GENE ARRANGEMENT				CHROMOSOMES EXAMINED
	Standard	Arrowhead	Chiricahua	Pikes Peak	
San Raphael Mts., Calif.	52.2	21.7	13.0	.....	92
San Jacinto Mts., Calif.	39.6	28.9	27.9	.....	4329
Western Death Valley region, Calif.	30.9	51.6	15.8	.....	2834
Eastern Death Valley region, Calif. and Nev.	17.4	71.1	11.5	.....	1194
Prescott, Ariz.	11.0	79.0	9.0	1.0	100
Flagstaff, Ariz.	1.0	97.0	1.0	1.0	100
Mesa Verde, Colo. ....	.....	100.0	.....	.....	100
Raton Pass, N. M. ....	.....	80.0	0.9	18.2	110
Trans-Pecos region, Tex.	1.4	35.9	3.5	53.5	142
North central Tex. ....	.....	21.5	.....	70.2	1315
South central Tex.	0.2	11.7	.....	70.3	418

distinct, the frequency of alleles among lethals must be a function of the source from which these lethals are derived. Recessive third-chromosome lethals were isolated from population samples of various stations on Mount San Jacinto. By intercrossing the strains containing these lethals, the frequencies of alleles among lethals found within a station, a locality, and a region were determined. These frequencies (in per cent) are as follows:

Within a station:

Collected simultaneously 2.081 ± 0.347
Collected at different times 1.961 ± 0.243

Within a locality:

Collected simultaneously 1.194 ± 0.243
Collected at different times 0.691 ± 0.173

Within a region

or in different regions 0.435 ± 0.119

to be somewhat less frequent in samples collected at different times than in those collected simultaneously.

One may now venture an interpretation of the above data. Obviously, this interpretation can make no pretense to finality, but it may be of interest as a temporary working hypothesis to be tested by further work. The differentiation of the species *Drosophila pseudoobscura* into highly local "races" suggests that the elementary breeding unit in this insect is characterized by a rather small effective population size. This is important because, as shown mathematically by Sewall Wright, a great evolutionary dynamism obtains in a species with small breeding units. The restriction of the effective population size in

Drosophila is presumably due to a sedentary habit of this insect, which imposes a limitation on the number of potential mates which any given individual is likely to encounter in its lifetime. It may also be assumed that the foods on which the insect subsists (the nature of which is, unfortunately, unknown) are unevenly distributed in its natural habitats. A few individuals which first reach a food supply will, then, produce a very large offspring, while a majority of individuals in a locality may leave little or no progeny. The offspring of the few "lucky" individuals will spread over the territory surrounding the place where they have developed, and impress their genetic characteristics on the whole population of a station or a locality. This is the probable explanation of the temporal changes in the composition of populations, an example of which is given in table I.

In contrast with the stated or implied assumption of most biologists that evolutionary changes are too slow to be observed within a human lifetime, we conclude that even in a species distributed over a continuously habitable territory the population may be in constant flux. The local races undergo rapid changes. Although these changes are essentially haphazard, they lead to the forma-

tion of numerous genotypes which, owing to the low frequencies of their constituent elements, would very seldom be formed in a large undivided population. Sewall Wright has shown that the formation by the species of such "trial parties" to explore the adaptive fitness of all possible genotypes is favorable for rapid evolution. The fleeting local changes may, then, be regarded as a source and a precursor of the permanent racial differentiation. Indeed, our data seem to show a series of conditions connecting the local breeding communities, with their constantly shifting composition, and the large-scale racial differentiation in major geographic regions.

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CHARLES ELTON, Bureau of Animal Population, Oxford University, Oxford, England. *Research upon natural fluctuations in North American animal populations*. (For previous reports see Year Books Nos. 37, 38.)

This research was continued, with the aid of a grant from the Carnegie Corporation of New York, administered by the Carnegie Institution of Washington. It falls into four sections: (1) the tracing of earlier fluctuations recorded in the history of the fur trade, and more especially in the archives of the Hudson's Bay Company; (2) a current inquiry into fluctuations of the arctic fox and associated species, through observers in the Canadian Arctic; (3) a similar inquiry into fluctuations of the snowshoe rabbit (or snowshoe hare), by means of reports from observers in Canada, the United States, and Alaska; (4) an investigation of the repro-

ductive rates of the snowshoe rabbit, done through men at Hudson's Bay Company posts.

1. A large amount of material has now been collected, in the shape of fur returns and descriptions of wild-life fluctuations, and this will be published in a series of reports dealing with different species, more particularly the snowshoe rabbit, lynx, colored fox, muskrat, arctic fox, and mice and lemmings. Mr. Elton has practically finished a book under the title "Voles, mice and lemmings: problems of population dynamics," which has been accepted for publication, and includes a full account of the arctic- and colored-fox

cycles (of about 3 to 4 years) in Labrador and Ungava (Quebec Peninsula), and their basis in similar cycles among voles and lemmings. This study also includes some account of the background of fur-trading conditions in those regions during the nineteenth and the present century. Owing to the war, further extraction of material from the Hudson's Bay Company's archives is held up; but attention is being given to thorough indexing and preparation for publication. It should be mentioned that the Hudson's Bay Company has adopted a very liberal attitude toward the release of such material for scientific research purposes.

2. Mr. Dennis Chitty studied and mapped the results of the Canadian Arctic Wild Life Enquiry for the season 1938-1939, and these are being published in the *Journal of Animal Ecology* in November 1940. This inquiry is carried out through observers organized by the Northwest Territories Administration of the Canadian Government and by the Hudson's Bay Company. The inquiry has now been done for four years, and the changing relations of arctic fox, snowy owl, and lemming have been clearly shown, especially in the eastern Arctic. This season a serious pandemic of sledge-dog disease, spreading from post to post, was clearly mapped through the inquiry. In the summer of 1939 Mr. Chitty was able, by courtesy of the Northwest Territories Administration and the Hudson's Bay Company, to join the SS. *Nascopie* at Fort Churchill and visit a number of posts in the eastern Arctic. This voyage enabled him to see the country and to gain firsthand acquaintance with the post managers who report in the Wild Life Enquiry, and information regarding the limits to which such a method of research should be pushed.

3. The major part of the Snowshoe Rabbit Enquiry is concerned with reports from Canada, supplied through the National Parks Bureau of the Canadian Government, the Hudson's Bay Company, and the Biological Board of Canada. The mapping of these

records for the season 1938-1939 was done by Mr. Chitty, who was able to introduce a new method of showing the results on a single map. This method both improves the clarity of presentation and saves labor in compilation. Mr. Elton worked out results, using the same method, for the eastern United States and Alaska (records supplied through the U. S. Bureau of Biological Survey). This year's report will be published in the *Canadian Field-Naturalist*. It shows the strong trend of recovery in numbers of snowshoe rabbits in many parts of Canada and the United States, and the final incidence of decrease in Alaska.

4. Mr. Elton has analyzed the results of an inquiry into the reproductive rates of the snowshoe rabbit, done by Hudson's Bay Company post managers according to a plan prepared at Oxford. Complete records were obtained for South Indian Lake post, Northern Manitoba, for 1938 and 1939. These showed three waves of reproduction each year, but hardly any difference in the average family size from year to year, at any rate in the first and second litters. The object of this inquiry is to test the truth of the widespread belief that there is a cyclical change in reproductive rates associated with the ten-year cycle.

The chief aim of all these investigations is to define more clearly the geographical distribution and historical continuity of two major wild-life fluctuations, the 3-4-year one in the Canadian Arctic and the 9-10-year one in the forest region of Canada and eastern United States. The reproduction inquiry is an attempt to begin that further and deeper stage of analysis which will have to be done by detailed scientific work at research stations in the country itself.

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ROBERT G. GREEN, University of Minnesota, Minneapolis, Minnesota. *Studies of viruses as related to cell proliferation.*

A study being made at the University of Minnesota of viruses as related to cell proliferation includes investigations of certain types of proliferative lesions of man, correlated with studies of similar tumors of animals. The work is financed in part by a grant from the Carnegie Corporation of New York, administered by the Carnegie Institution of Washington.

Host specificity is a factor of major importance in studying the biology of proliferative viruses. Both species specificity and histologic specificity are developed to the greatest degree in those viruses which induce proliferation of host cells. Experiments designed to modify the specificity of viruses by utilizing their adaptability or variability to broaden the range of susceptible host species and tissues have been under way for several years on proliferative viruses of human beings and lower mammals. These studies have met with some success, as will be described below.

The canine oral papilloma has been passed through several generations in dogs, but apparently cannot be induced to grow on the closely related red fox, *Vulpes fulvus*. Though the Shope papilloma virus derived from cottontail rabbits can be transmitted to the domestic rabbit, serial passage of the virus through the latter results in failure within the first few generations. These represent the same obstacles as are encountered in trying to induce papillomas of human origin to grow in monkeys. Modification of species specificity is a prerequisite to any extensive investigation of proliferative viruses of man, since very few procedures can be carried out on human volunteers.

Even more striking than this specificity regarding susceptible animal species is the histologic specificity exhibited by proliferative viruses. The canine oral papilloma, which grows easily on the mouth of a dog, does not ordinarily grow on the skin or other epithelium of that animal. In these investigations a strain of virus from a canine oral papilloma has been induced to grow on the

epithelium of the cornea and on the epithelium of the eyelid of a dog. It was carried two generations; the papilloma resulting in the second generation, however, regressed much more quickly than that in the first. Although the initial step has been successfully completed, adaptation to a new type of epithelium is by no means complete.

In the course of several hundred inoculations of human tumors into monkeys, one experiment resulted in the transmission of a papillomatous tumor from a human being to a *Macacus rhesus* monkey. A cutaneous horn from the eyelid of a man was injected into the ocular tissues of three monkeys and produced a small tumor in each of them at the site of inoculation. Histologic study of two of these lesions showed them to be composed principally of conjunctival epithelium which had undergone focal proliferation at the site of inoculation. The third lesion was used in a belated attempt to retransmit the tumor. This was the first time in these studies that a proliferative virus had been adapted sufficiently to span the zoological gap between man and monkey. The experiment indicates that, given an adequate number of trials and appropriate technique, it will be possible to adapt proliferative viruses of human origin to continued growth in monkeys. A detailed report of this experiment appeared in the June 1940 issue of the *American Journal of Cancer*.

Present work is centered around the use of new equipment which has been installed for these experiments. A specially built homogenizer is employed to liberate the virus and other constituents of the tumor cells into a fluid medium. The fluid is then placed in an air-driven ultracentrifuge of the Beams type, which concentrates and purifies the virus. It is believed that this procedure will free the virus from any inhibitory substances and will concentrate it in large enough doses to make available virus variants or mutants which may bridge the gaps of histologic and species specificity and allow more consistent trans-

mission of tumors between unlike species. This seems essential for the study of human tumors as related to the presence of a filterable virus.

ARTHUR T. HERTIG, Boston Lying-in Hospital and Free Hospital for Women, Brookline, Massachusetts. *Research in embryology and embryological pathology.* (For previous reports see Year Books Nos. 36-38.)

These studies have been continued with financial support of the Carnegie Corporation of New York, administered through the Carnegie Institution of Washington.

Since the last report, the studies on the genesis of hydatidiform degeneration have been essentially completed. The main report on this work has appeared in the *Archives of Pathology*, as a joint paper with Dr. Henry W. Edmonds, a research fellow of the Department of Obstetrics, Harvard Medical School.

The study on the pathologic-clinical correlation in mature hydatidiform moles has been furthered during the past year by continued opportunities to obtain specimens from outside clinics in addition to those from our own. The coming year will probably see assembled a large enough series of cases of this relatively uncommon condition to warrant conclusions as to the morphologic criteria of malignancy in these specimens.

During the past year the two normal human ova referred to in Year Book No. 38, page 282, representing the two earliest complete examples of human development, have been extensively studied by means of plastic reconstructions. A plastic material, cellulose acetate, manufactured by the Monsanto Chemical Company, facilitated this study considerably. From these reconstructions it has been possible, for the first time, to study the relations of maternal endometrial vessels to the recently implanted human ovum. Large, thin-walled endothelium-lined sinusoids develop by hypertrophy, hyperplasia, and dilatation from capillary anastomoses between the spiral arterioles and endometrial veins. Secondary offshoots of these sinusoids are sub-

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sequently tapped by the trophoblast of the growing ovum to furnish food for embryonic growth. The detailed description of these two specimens has been completed and will appear in the next volume of "Contributions to Embryology."

Search for additional early human ova has been continued during the past year. Four such specimens have been recovered in uteri removed for various therapeutic reasons before the expected menstrual period had been missed. Two of the specimens are not entirely normal—a fact of great significance in studies on pathogenesis of spontaneous abortion. These two ova, thought to be the earliest pathological specimens thus far observed, will permit the study of normal as well as abnormal developmental processes, since not all of each specimen is entirely defective. Thus, one of the specimens appears defective as regards its chorionic development but normal with respect to the embryonic rudiment. This happens to be in a critical stage with respect to yolk-sac development, a phase about which there is, at present, no universal agreement. Of the two remaining specimens, only one has been sectioned, but the other represents a phase of human development at about the 15th day. Only one other example of this stage has thus far been seen, the Peters ovum, described in 1899. It is believed that more modern methods of fixation and preparation will make it possible to gain new information from such specimens.

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T. H. MORGAN, JACK SCHULTZ, and VIOLA CURRY, California Institute of Technology, Pasadena, California. *Investigations on the constitution of the germinal material in relation to heredity.* (For previous reports see Year Books Nos. 15-38.)

The study of the constitution of the germinal material in relation to heredity has acquired new meanings as information has increased and methods of attack have become more diversified. In the early days, the cytological methods served as a crude supplement to the more refined genetical analysis, by means of which the finer topography of the chromosomes was worked out. With the discovery in more recent years of the giant chromosomes, and the elaboration of chemical and particularly optical methods for their analysis, the problem has taken on a different aspect. It turns out that the various regions of the chromosomes have their specific chemical characteristics. Thus the genetical material and the exact knowledge of the location of the different types of mutant genes now become basic to the eventual analysis of the functional meaning of the structure of the chromosome. The work to be done with the material takes its departure from various directions toward the same goal. It is necessary to make the controlled genetical material usable for cytochemical work, so that changes in the genetical structure of a chromosome region may be correlated with a cytochemical analysis of that chromosome region. It is necessary to determine whether there is any order in the arrangement of the genes on the chromosome as related to their phenotypic effect and to determine what interrelations there are between the effects of genes in the various tissues—a question which touches on the embryological problem of differentiation. The results of such researches may then be examined in connection with the chemical data on the chromosomes.

It is evident from such a statement of the present development of the field that the cytochemical analysis of the exchanges between nucleus and cytoplasm in the different tissues of the organism is of paramount importance in the determination of the nature and activity of the gene. Stated in chemical terms, the problem resolves itself (since the

chromosomes are nucleoprotein in composition) into a study of the metabolism of the nucleoproteins. During a two years' leave of absence, working with Dr. T. Caspersson at the Chemical Laboratory of the Caroline Institute in Stockholm, Schultz has studied these problems. Some of the results have already been published; others are in preparation for publication. It appears from the work (see the reports in Year Books Nos. 37 and 38) that the nucleic acid compounds of the nucleus and cytoplasm have an especial importance in the processes of synthesis. Tissues in which rapid growth or cell division is taking place have high concentrations of ribonucleic acids in the cytoplasm. Measurements of the absorption spectra of the cytoplasm during growth of the salivary gland in *Drosophila* have shown that, in this case at least, as the concentration of nucleic acid decreases, the protein rises, which is consistent with the hypothesis that ribonucleic acid compounds are important in protein synthesis. It has been shown that these ribonucleic acid compounds are present in the nucleus also, specifically in the nucleolus, and analysis of data on a variety of genetic types has shown that the composition of the nucleolus is genetically determined. Moreover, it appears that the heterochromatic regions of the chromosomes, which are of importance in the determination of variegation, are influential in modifying the character of the nucleoproteins of the salivary-gland nucleolus. These results, taken together with the differences established by optical methods in the nucleoprotein composition of the heterochromatic and euchromatic regions, give promise that continued study of the detailed correlation of cytochemical and genetical data will permit a direct analysis of the workings of the genes.

The genetical properties of heterochromatin itself, which come to the foreground because of the chemical differences between these regions and the so-called "euchromatic" re-

gions, have just recently been studied further by Schultz and Mrs. Curry. Previous studies (see the reports in Year Books Nos. 34-38) have shown an association between these regions and the process of variegation, involving changes in the nucleoprotein metabolism of the regions juxtaposed to heterochromatin in rearrangements, correlated with the occurrence of genetically detectable changes in the somatic tissues.

The properties of the regions have not been studied very much from other points of view except in the X chromosome, where it has been shown that the deficiencies and duplications of heterochromatic material have relatively little phenotypic effect. The role of heterochromatin in the autosomes, where the balance is different, needs more study. The heterochromatin of the right limb of the second chromosome is advantageous material; for in this region a number of spontaneous mutants are available, and also a group of deficiencies, studies of some of which were reported last year.

The region in question has its locus on the salivary-gland chromosomes in the map sections 41A to 42A. Sections 41A and B are heterochromatin in the strict sense. These form part of the chromocenter, showing the property of indiscriminate synapsis with other heterochromatic regions. Less frequently the same property is shown by 41C and D. The large capsule of 42A rarely shows evidence of being heterochromatin. The total number of lines in this section of the salivary-gland chromosome is 33 according to the 1940 map. A group of seven mutant genes has been localized here, giving a mutation coefficient of 4.7. This is in distinct contrast with the low coefficient in the adjacent region (42A-44A), where seven genes are localized in 127 bands. From their phenotypes alone, the genes located within the heterochromatic region are not to be distinguished from mutants in general.

Deficiencies for this region (41B-42A) have been obtained from crossing over between overlapping inversions. Flies carrying these survive in heterozygous form and are "Minute" in character, relatively viable but

with a pale body color. Tests of the seven mutants of this region show that all are included with the exception of the mutant "rolled," which is farthest to the left. Similar results have been obtained with the comparable X-ray-induced deficiency, $Df(2)M\text{-}vg^{11}$, which resembles the other deficiencies in phenotype as well.

In this region, as has been reported previously, there is a group of shorter deficiencies, also Minutes. The analysis of the interrelations of these with each other and with the loci included in this region has shown that there is a single Minute locus to the right of "rolled" and to the left of "straw"; and that "blot," "thick," and "apterous" are to the right of these loci, as was known from the localization experiments. The dominant pale body color is shown only in those Minutes that are deficient for straw (which is located in this region just to the right of rolled) or contain a change at the straw locus as determined by crossing to straw. Such are $M(2)D$, $M(2)S_2$, $M(2)S_4$, and $M(2)S_8$. The deficiency $M(2)S_{10}$, which is lethal with these, does not show the pale body color and shows no interaction with the recessive straw. It does show, however, when heterozygous for the mutant rolled, the characteristics of this mutant in somewhat more extreme form than the homozygous recessive. Hence the Minute locus common to all these deficiencies lies between rolled and straw; and all the Minutes in the region (detected as Minutes in the same X-ray experiment) are deficient for one or the other of the loci, rolled or straw.

The phenotypic effects exhibited in individuals heterozygous for the deficiency and the recessive change included within it are, in all the cases in this region, of the usual type observed in tests of mutants against deficiencies. We have found "exaggeration" effects in the case of $M(2)S_{10}/\text{rolled}$, and with the straw allelomorphs against deficiencies for straw, where the phenotypic characters of the mutant are exhibited in their most extreme form for each allele. The mutants blot, thick, and apterous are likewise exaggerated when appearing in heterozygous form against the

longer deficiencies which include them. The mutant "misformed," a variable character at best, is consistently a more extreme character against a deficiency for that locus. Thus, as in the case of bobbed in the X, the mutant genes in 2R heterochromatin show quite normal relations with dosage changes.

The effects at points of rearrangement in this region have previously not been studied systematically except in relation to an influence upon the variegation process. Rearrangements having one point of breakage in 41A or 41B and the other near the white or brown region show the variegation characteristics of all translocations involving these regions and heterochromatin. But the effects upon genes within the heterochromatin itself must also be studied, especially since there may be a reciprocal relation between the effects on the genes within heterochromatin and those without, already discussed in previously studied cases. A beginning has been made of such an analysis for this region. A translocation, symbolized T(Y;2)B, having a break in 2R at 41A, has already been reported to contain an extreme allelemorph of rolled, giving a much more extreme phenotype when heterozygous for the recessive mutant than does M(2)S10 when heterozygous for rolled. T(Y;2)B is lethal with M(2)S10, but the other deficiencies discussed above (which lack the effect upon the rolled locus) give normally appearing heterozygotes with T(Y;2)B. Thus M(2)S10 and T(Y;2)B, possibly as a result of their common effect upon the rolled locus, have a lethal effect together.

A complicated inversion, symbolized In(2LR)dp, has a break point near by, worked out by Bridges as between 41A and B and thus toward the distal end of the M(2)S10 deficiency. This rearrangement has a lethal effect with M(2)S10; is normal with T(Y;2)B; and shows wing and scutellar abnormalities over the deficiencies to the right of rolled ($Df(2)M\text{-}vg^{11}$ and the inversion cross-over deficiencies) which are not otherwise displayed either by In(2LR)dp or these deficiencies. It is to be concluded that we are dealing with a series of effects upon loci distal and proximal to the point of rearrange-

ment, of which the proximal (with respect to the spindle attachment) gives the lethal effect with M(2)S10, and the distal the extreme combination effect with the other deficiencies. Farther to the right is another rearrangement ("Xasta") associated with a dominant incision of the wing in the marginal cell, and with a breakage point in the salivary-gland chromosome at $42A \pm$ (Bridges). This rearrangement gives an ordinary superposition of phenotypes over M(2)S10, but with a longer deficiency gives a combination which has a phenotype similar to that of the rather inviable homozygous Xasta, somewhat pale in body color, and with wings reduced to rudimentary sacs. The only wing character included in this deficiency is blot, crosses of which to Xasta give a heterozygote showing both characters. It follows that the "Xasta" effect is in part associated with the blot locus, a point of some interest since according to Waddington the embryological processes involved in the formation of the very different wing patterns are not immediately related.

From the foregoing it is evident that the genes which happen to be located within this region of heterochromatin are not especially distinguished in their phenotypic reactions from the usually studied genes. It is indeed uncommon that a deficiency of the length of the heterochromatin section here discussed should have so many mutants included—a point which may indicate either a high survival rate of the mutants or mutability of the genes in this region. This could be of significance in relation to the variegation induced by heterochromatin in the rearrangements; but so far there is no evidence other than this which gives a reason for associating the phenomena of somatic variegation with those of germinal mutation. It may be, of course, that these mutants are the result of small rearrangements to which (Sidorov, Muller, Belgovsky) heterochromatin is especially prone. But by and large the genes in this region, as determined by the mutations which they give, are not unusual.

It is, however, another matter when tests are made of the effects of the deficiencies upon the process of variegation specifically

associated with heterochromatin. The combination of the various deficiencies in this region with the variegated types (mottled whites, browns, Revolute, etc.) has shown that the deficiencies $M(2)S10$ and $M(2)D$ both exert an effect equivalent to that of the removal of a Y chromosome in enhancing the variegation. A rearrangement, which at 25° C. shows no mottling for white or notching of the wings, when combined with $M(2)S10$ at 25° C. is an extreme Notch, and shows extensive mottling resembling the lighter allelomorphs of white. Thus a deficiency for a portion of the heterochromatin of $2R$ shows the same relation to variegation as deficiency for the Y chromosome. Other types of experiment show that duplication of the region suppresses the variegation. The evidence is clear that within this region there is a section of typically "heterochromatic" properties.

Analysis of the metaphase chromosomes in $M(2)S10$, which appears in the salivary-gland chromosomes to be deficient for at most several bands (41A), shows that we have here a situation similar to that of the heterochromatin in the X. The deficiency of a short section of the salivary-gland chromosomes appears to be correlated with the loss of about one-fourth of the metaphase length of the chromosome arm, as in the case of the "blocks" of the X chromosome (Muller, Prokofyeva, Gershenson). The locus of the block in this case appears to be between the locus of rolled and the Minute of this region, since $M(2)S10$ (deficient for rolled but not for straw) and $M(2)D$ (deficient for straw but not for rolled) both lack the heterochromatin influencing variegation. The evidence is then strong that in this region genes possessing all the specificities of the "euchromatic" genes may reside in heterochromatin, and that heterochromatin proper may be intercalated between such genes.

Special circumstances, developing from the preparation for publication in book form of the late Dr. Bridges' symbol list of *Drosophila* mutants, by Dr. Brehme at Cold Spring Harbor, have made it necessary to devote much time this year to checking the descriptions

against the mutant races available in the stock room here, and against the original data. As a by-product of this work, it has been possible for Schultz and Mrs. Curry to make a beginning at the systematization of the effects of genes upon developmental processes in different tissues.

The problem at issue is one that has been studied previously for special genes. A mutant change has usually a special and striking effect upon a pattern of characters: thus in one mutant, certain bristles may be lacking, and the wings always at right angles to their normal position, whereas in another only a similar wing effect occurs. In addition to such striking major effects, each mutant has a constellation of minor effects. It is evident that such associations may be specifically related to the several genes, or they may be due to similarities of the developmental processes involved. Comparison of such associations in a population of mutants, whose effects are classified so that a statistical analysis can be made, should be useful toward an understanding of their meaning. A beginning of such an analysis of the mutant races available has already been made for the mutants of the X chromosome. Each mutant was classified for the presence of abnormalities in any of forty selected characters, which as it turned out were sufficiently well selected so that among the majority of the mutants, each had its individual pattern of effects. It must be recognized that in such a population of mutants, associations between the occurrences of different attributes in the various genes depend upon several different factors. Only those mutants can be obtained as viable races in which harmonious combinations of developmental reactions occur; thus the population of mutants is by no means random, but is a group selected for survival among changes detectably different from the wild type. Nevertheless, even with this reservation, analysis of the data permits some conclusions about the relations between the sensitivities to genetic changes in the developmental processes in the different tissues.

The frequency of occurrence of each attribute in the population was determined, and

also the frequency with which each pair of attributes occurred. The expected frequency for the occurrence of associated pairs (the product of their total frequencies in the population) can then be compared with the observed frequency, and an indication obtained of any tendency for association of special pairs. Such an association has in fact been found for a number of pairs of attributes. Some of these are associations of different effects on the same organ; for example, the abnormalities of the size of the eye and the structure or arrangement of the ommatidia tend to be correlated, indicating that a mutant affecting either the structure or arrangement of the ommatidia is likely also to affect their number. More interesting are the correlations of effects upon different organs. For example, 6.8 per cent of the mutants affecting the size of the eye also affect the fertility of the female, where on a random association of the characters only 2.6 per cent would be expected. Another example occurs between the attribute "ommatidial arrangement" and the various developmental changes in the wing—changes in the margin, etc. (8.7 per cent found; 3.7 per cent expected).

These correlations necessitate a consideration of possible similarities of the developmental processes involved. According to Waddington's analysis of the development of the wing in *Drosophila*, the different mutant types resolve themselves into what are essentially changes of rate of cell division, patterns of growth and movement of the cells in the organ. Stated in these terms, the problem becomes one of determining the similarities in the morphogenesis of the eye and the wing, which would allow an interpretation of the differences as resulting from effects of the gene changes upon homologous processes in the development of the different organs.

The apparent existence of such homologous processes permits a new approach to the

problem of the arrangement of the genes within the chromosome. The general postulate that this arrangement is random has long been suspect, particularly since Bridges' analysis of the salivary-gland chromosomes into patterns of duplicated sections. Especially relevant has been the presence of extraordinarily similar mutants side by side in a number of cases. But there has been no general analysis. With the more detailed classification of the mutants outlined above, such a general analysis becomes more possible, and it is now under way. A preliminary indication of the nature of the results comes from an analysis of the association of dominant notch wing characters with mutants showing ommatidial disarrangement. In the whole series of *Drosophila* mutants a group of seven such mutants has been found: Notch, the dominant vestigials, Beaded, Beadex, Jagged, Serrate, and Lyra. Of these, all but Beaded and Beadex have as the closest mutant on one side or the other a mutant involving disarrangement of the ommatidia. The probability, on the assumption of random distribution, of such a frequency of association of the two types (five out of seven pairs) is only about one in a thousand. It seems likely that for some cases at least the distribution of the genes on the chromosomes is not at random. Further analysis of the association of the different pairs of attributes should permit a more detailed statement of the problem, and a decision between the various different possibilities.

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E. G. RITZMAN, University of New Hampshire, Durham, New Hampshire. *Cooperative researches on the nutritional physiology of the adult ruminant.* (For previous reports see Year Books Nos. 37, 38.)

Further progress in the cooperative studies on the nutritional physiology of dairy cattle can be recorded at this time. This year's study on the requirements of growth and factors affecting it was carried out on that immature period of development when the cattle had passed the stage at which they depend entirely, or in part, on a diet of milk.

Four purebred Holstein heifers, 4 months of age and carefully selected to supply two physiologically matched pairs, were purchased for this purpose. During the 7 months of the experiment, that is, between October 1 and May 1, 20 basal-metabolism experiments and 12 complete balances of ingo and of outgo of matter and of energy were carried out. The results of these balance experiments are of particular interest, as no such extensive studies had been made before this on dairy stock at this stage of growth. These results show that computed energy provisions of the feeding standards now available correspond closely to the results obtained by this carefully determined balance, but that these calves made an average growth increase of nearly 2 pounds a day on a protein intake 28 per cent below the published standard provisions. The basal metabolism fell from 20,470 calories (per 500 kg. weight) at 4 months of age to 12,015 calories 7 months later, thus demonstrating again, as has been done in the case of sheep, goats, and pigs, the extraordinary tissue stimulus that characterizes growth.

The observations on the effect of visual light on basal metabolism and other physiological activities have also been continued. One pair was kept in darkened stalls during the entire 7 months, while the other pair was exposed to the lighting conditions described in last year's report. Data on blood constituents showed no difference between the two pairs. However, at 4 months of age the blood sugar was distinctly lower than the minimum value for the normal range of 40 to 60 mg. per 100 cc. of blood given for adults

(Dukes, *The physiology of domestic animals*, p. 48, 1937), although normal values prevailed at 6 months. Nonprotein nitrogen, on the other hand, was at the maximum level or in excess of it at 4 months and at about the minimum at 6 months. Blood calcium and inorganic phosphorus corresponded closely to the normal values given for adults. Pulse-rate and rectal-temperature observations obtained during the entire period show no measurable differences between the four individuals. No appreciable difference was observed in the basal metabolism between the pair which had been kept in darkened stalls and the pair which had been exposed to artificial light. There is a tendency for a higher basal metabolism in favor of light, but the difference for the entire period, covering four experiments per animal, is only 2 per cent. It seems thus apparent that visual light exerts no material influence in stimulating the basal metabolism at this early stage of life in dairy cattle. The extent to which any such effect of light may possibly have been disguised by the extraordinary stimulus associated with growth could not be determined. These studies will be continued.

A series of experiments has been carried out this year on the effect of drawing loads of different weight and resistance, and at different speeds, on the energy expended by the horse in performing work. The apparatus mentioned in last year's report for measuring the energy expended by the horse was used, and the load resistance was measured by means of a new type of drawbar dynamometer designed by the Department of Agricultural Engineering and built by the Instrument Shop of the University of Missouri (Missouri Agricultural Experiment Station, Research Bulletin No. 226, 1935). The results of six experiments in which a stoneboat was used as the vehicle, to which varying degrees of load were added, are shown in the accompanying table. The cost of pulling load

increased per pound pull from 14.5 calories at 160 pounds resistance to 25.0 calories at 250 pounds resistance.

These experiments were all carried out with a single horse (Percheron gelding weighing 1350 pounds), but similar tests under field conditions in which this horse is used with his team mate are now under way to measure the energy cost of farm work. Preliminary trials with the dynamometer in

plowing indicate still higher resistances than those shown above, 300 to 350 (per horse) for stubble and 400 to 500 for sod.

Although the results so far obtained suggest broad possibilities in the study of farm problems and particularly in helping to supply a more accurate measure for comparing the relative efficiency of horse and tractor, it would be premature to discuss these results further until the whole series is completed.

PULL (lbs.)	SPEED OF PULL (mins. per mile)	ELAPSED TIME (mins.)	DISTANCE (yds.)	ENERGY EXPENDED PER HOUR		
				Total with load (cals.)	Walking without load (cals.)	Cost of pulling load (cals.)
160....	19	10	913	5040	2740	2300
195....	20	5	435	5435	2145	3290
195....	20	10	884	5450	2145	3305
225....	18	5	478	7630	2740	4890
235....	21	5	417	7380	2145	5235
250....	18	5	478	9000	2740	6260

H. C. SHERMAN, Columbia University, New York, New York. *Research on influence of nutrition upon the chemical composition of the normal body.* (For previous reports see Year Books Nos. 32-38.)

It has long been an influential theory that the chemical composition of the normal body of a given species, sex, and age is essentially constant. This alleged *fixité* of our internal environment was cited as explanation of our ability to survive in a new or changing external environment.

Recently, however, it has been shown that, starting with a dietary already adequate and a bodily condition already normal, the life process may be improved by enriching the nutritional intake in certain of its chemical factors. Thus it becomes an important question how far the chemical composition and internal environment of the normal body actually varies; especially, how far we can improve the body's internal chemistry through scientific management of its nutritional intake. This we are studying experimentally with the aid of a grant from the Carnegie Corporation of New York through the Carnegie Institution of Washington.

In experiments extending throughout the

entire life cycles of at least two generations of well controlled laboratory animals, it has been found that calcium, riboflavin, and vitamin A each has the property of conferring successively increased benefit through successively increased nutritional intake up to levels more than twice that of minimal adequacy. It is of scientific significance to determine how far this is due to measurable increases of the concentration levels of these chemical factors in the body; that is, to improvement of the internal environment through nutritional control.

Our experimental investigation of the calcium content of the normal body as influenced by nutritional conditions has now been completed. Working from four different dietary starting points, we find that the rate of normal increase in the percentage of calcium in the growing body rises with the calcium content of the food up to a level of intake three to four times that of minimal adequacy. Moreover, by extended study of the results of

feeding our Diet A, the adequacy of which has been further established by the fact that laboratory animals are now thriving upon it in the fiftieth generation, it is found that even in adult life the percentage of calcium in the body does not on this diet attain fully to the level reached with food of a more liberal calcium content.

It is striking to find that the more liberal calcium level proves to be so potent a means of improving the normal life process when we know that the greater part of the extra calcium thus acquired from the food is laid up in the body in the very sparingly soluble form of bone salt. The explanation appears to be that much of this extra material takes the form of an increased development of bone trabeculae with resulting increased area of contact between "stored calcium" and circulating blood, so that the concentration of calcium in the blood is kept more constantly in the upper ranges of the normal zone. Internal environment, as the now converging viewpoints of physicochemical principle and nutritional experimentation are beginning to make clear, is largely a matter of zones rather than of fixed levels of normality; and calcium is now established as one of the chemical factors whose optimal concentration is at or near the top of the normal range or zone.

Our findings are further clarified by two related series of analyses just completed. In the first of these, large numbers of normal growing animals of the same age, sex, hereditary background, and food supply have been analyzed to determine the influence of individual differences in rate of growth and resulting size at a given age. In such cases, with the normally growing and developing body increasing both its amount and its percentage of calcium, it is found that the latter is essentially determined by age and not by size.

Meanwhile in the second of these complementary series we have studied the results of interlocking variations of the calcium and the protein content of the diet. Three levels of protein intake were studied: 14, 18, and 25 per cent of the dry weight of the food, the increase of protein tending in these cases to

increase moderately the rate of growth. At each of these protein levels, an increased percentage of calcium in the food was found, as in previous experiments already reported, to increase the percentage of body calcium at a given age; but with food of a given calcium content, an increased growth induced by enrichment of protein intake did not result in a higher percentage of body calcium at a given age, as would have been the case if the acceleration of growth by the higher protein intake had correspondingly accelerated the body's rate of progress toward skeletal maturity.

The findings of the three independent but mutually enlightening researches upon body calcium content, thus briefly outlined, are now being prepared for journal publication.

During the past year it became economically possible to begin the feeding of statistically satisfactory numbers of animals with rations in which isolated riboflavin (previously called vitamin G) was the sole variable. Previously it had been found, in other laboratories as well as our own, that the tissues of animals whose food had been practically devoid of riboflavin contained less of this substance than did those of animals normally nourished. Our present experiments with systematically graded levels of intake yield the further finding that the riboflavin content of the body is markedly lowered when an adequate level of feeding is reduced even by one-half. The converse question of the effects of surplus intake upon the concentrations of riboflavin in body tissues is proving to be more complicated. Though these higher levels seem to enhance the well-being of the original individuals and their offspring, our measurements do not yet establish the exact limits within which the intake influences the concentration in the body. Further experimental work on this point is now in progress.

Our studies of the influence of nutritional intake upon levels of vitamin A content in normal body tissues are also in active progress. Both when the starting point is our Diet A, of little more than minimal adequacy in its calcium, riboflavin, and vitamin A content, and when it is the more liberal and better

balanced Diet B, increased feeding of vitamin A increases the concentration of this substance in the liver in readily demonstrable degree, but has only a questionably measurable influence upon the vitamin A content of the muscles. Apparently under even very liberal nutritional conditions, the muscles contain so low a concentration of vitamin A as to be practically at the limit of present methods of measurement, some investigators reporting that muscle contains none of this factor. Our current experimentation seeks both to improve the delicacy and precision of methods and also to extend their application to larger numbers of carefully controlled cases. A technique sufficiently developed to yield satisfactory results with muscle will presumably be adaptable also to other bodily tissues, as some of these resemble muscle in their vitamin A content, whereas others are inter-

mediate between muscle and liver in this respect.

We plan to continue experimentation with riboflavin and with vitamin A as actively during the coming year as available resources permit.

Our present experimental program seeks to find how much farther than science has hitherto supposed it is possible not only to correct deficiencies but constructively to advance the norm of the internal chemistry and thus of the life process by nutritional means. For the study of this question we now have in the long-controlled, laboratory-bred colony of experimental animals an instrument of research such as has not existed before.

The generous and efficient service of those who have collaborated in the work here reported, whether as research assistants or as volunteers, is gratefully acknowledged.

DIVISION OF HISTORICAL RESEARCH

Cambridge, Massachusetts

A. V. KIDDER, *Chairman*

The major activities of the Division during the past decade have been study of Maya history and of the history of science, both backward-looking researches the utility of which, in these cataclysmic days, cannot fail to be questioned, both by the men engaged upon them and by those responsible for their administration. Just as we of the staff have been asking ourselves why we are counting prehistoric potsherds, or wrestling with the problem of forced labor in sixteenth-century Yucatán, or striving to gauge the influence of Aristotle on medieval physics, so the officers of the Institution must have been wondering whether they are justified in continuing to sponsor the investigation of scientific theories long since outmoded and, even more, why they should promote study of an Indian people whose glory had faded some centuries before Columbus landed and who today are but humble soil-tillers ruled by the descendants of their European conquerors.

Such doubts must trouble all who are now concerning themselves with any but the most urgently practical affairs. Nevertheless, if civilization is to persist, it seems essential that the study of man should go forward and should be broadened and deepened and rendered more precise.

We need, as never before, to know the capabilities and the weaknesses of the human race and to understand the fundamentals of the man-culture relationship, because the mighty machine which science's control of the physical world has permitted us to build exercises its unlimited power for good or for evil only as it is directed by man. That machine, however, now seems in danger of being run for wholly destructive purposes. We are given to thinking of this as something new, but every major invention from the paleolithic hand ax to the airplane, though at first bringing material benefit, has sooner or later created social and economic problems

so complex that, lacking sufficient understanding of ourselves, we have, as a rule, been able to solve them only by repeated resorts to the brutalizing and cruelly wasteful expedients of war.

Knowledge of the history of science will certainly not enable us to combat the immediate dangers which menace us. But if the present storm be weathered, how can we hope to build soundly for the future of a world in which the products of science will inevitably play so great a part, if we do not understand their development and the effect they have had in the past upon philosophies of life and upon governmental practices? Likewise, though the career of the Maya has even less bearing upon the problems of the moment, it gives opportunity for study of the rise and spread of a culture, the dominance of absolute rulers, political rivalries and civil wars, the decline and eventual fall of a virile civilization, submission to foreign military conquest, adjustments between a dense native population and a small class of alien overlords. Such events and such situations have shaped the course of history at all times and throughout the world.

One does not, of course, pursue researches upon the nature of combustion while the house is burning over one's head—one runs for a fire extinguisher. That essential instrument, however, was developed on the basis of physical and chemical knowledge, whereas our comprehension of the physics of the human atom and the chemistry of social and political reactions is so pitifully limited that, in our ignorance, we can do no better than tear apart with war the painfully erected structure of our civilization.

It seems, then, to the historian and the anthropologist that the study of man must at all costs be continued, even though it be long and slow. It cannot be otherwise, because man is so complex a creature, because so

much of significance regarding his past can only with the greatest difficulty be recovered, and because the fundamental aims of humanistic research have not generally been grasped nor have the most effective methods for attaining them been worked out. The development of methods has, indeed, always constituted a primary objective of the Institution's historical activities. Dr. Jameson and his colleagues, through their insistence upon thorough and accurate utilization of documentary materials and their rendering available of such materials by publication of archival guides, played an outstanding role in the establishment of sound historical scholarship in the United States. Dr. Sarton has devoted his entire career to the collection and interpretation of data upon the lives of scientific leaders and upon the spiritual and intellectual environments which conditioned their activities. He has put into practice a firmly held belief that the history of science is more than the sum of the histories of individual sciences and that only through synthesis of all positively determinable and pertinent facts can valid conclusions be drawn regarding the all-important matter of the growth of scientific thought and as to its effect upon the course of history.

Most recently, the Institution has sponsored a survey of the entire range of Maya history, a study supplemented by research upon the varied environmental factors which throughout the centuries have influenced the career of the Maya and their Spanish conquerors. This investigation throws light upon events in the pre-Columbian New World. It has even wider bearings upon general anthropological theory. It is also of immediate practical service in bringing greatly needed understanding of present-day conditions in the large parts of Latin America where dense Indian populations have been brought under European control. Yet its greatest value should accrue from the development of methods for comprehensive, coordinated, cooperative research which, if successful in the relatively simple case

of the Maya, can be perfected and broadened for attack upon the vastly greater and far more complex historical problems which must eventually be solved if we are to attain real knowledge of man in the modern world.

The foregoing is, of course, the special pleading of anthropologists and historians for opportunity, in these rapidly changing and materially minded times, to continue their researches. Research, however, is more than the gathering and recording of facts in the hope that some day someone will be able to make use of them. Synthesis of raw data, the erection and testing of hypotheses should constantly go on, not only in order to avoid useless exploration of blind alleys and to indicate new means of approach, but also to permit the generalizations which are the only form in which the results of specialized investigation can be made really effective, through their dissemination to workers in allied disciplines and to the intelligent layman.

The preparation of their product for these essential markets is a matter which should be of special concern to members of an agency, such as this Division, which is devoted to pure research in the humanities. The university historian or anthropologist must put his findings into coherent form, draw conclusions therefrom, and hand on both summarized facts and conclusions to his students. The museum curator, if he be more than a mere hoarder, does the same in the selection and display of his specimens. But the man who has no stated duties beyond research is less urgently moved to marshal his materials and has no obvious public beyond a small group of fellow specialists. Yet the data at his command are abundant, fresh, often highly significant; there is no call upon his time or his energies for routine teaching or museum administration. It would therefore seem that one of the definite objectives of every research man should be the writing of books or articles for a wider audience than is reached by his scientific reports.

ARCHAEOLOGY

The past twelve months have been devoted largely to digestion of the great amounts of new information gathered during the intensive field investigations of the middle and late thirties. Completion of the resultant reports and work involved in their passage through the press will continue to occupy a considerable amount of staff time during the coming year. Nevertheless, a number of important projects have gone forward. Archaeological explorations in Yucatán were resumed, Dr. Pollock and Mr. Shook spending three months among the little-known ruins of the western part of the peninsula, and Mr. Andrews making a reconnaissance, under very adverse conditions, of an area in Campeche and Tabasco which has hitherto constituted a blank space on the archaeological map. In Guatemala, Mr. A. L. Smith conducted excavations at San Agustín Acasaguastlán in the Motagua valley, discovering two vaulted tombs containing fine examples of the beautiful pottery of the late Old Empire. He also worked out the range of what he has called the Middle Motagua culture, listing well over a thousand mounds of the peculiar San Agustín type. Mr. Strómsvik, assisted by Mr. Lee, continued the excavations and repairs at Copan which Carnegie Institution, with the aid of the Honduranian Government, has been engaged upon since 1936. During the past year, Mr. Strómsvik completed resetting of the great Hieroglyphic Stairway and cleared of debris and consolidated the walls of two temples flanking the ball court. Mr. Shook, in addition to his work with Dr. Pollock in Yucatán and with Mr. Strómsvik at Copan, accompanied Mr. A. L. Smith to Uaxactún to make observations needed for completion of the report upon that site. He also surveyed a previously unmapped section of the Kaminaljuyu ruins and made a brief reconnaissance of the ruins of Rabinal. Dr. Brainerd has been working upon the collections of Yucatecan pottery in storage at Chichen Itzá, and Miss Shepard has continued her researches in ceramic technology.

Progress upon reports has been notable. Dr. Morley and Mr. Roys have brought nearly to completion their study of the Xiu family, rulers of Uxmal, and of their descendants to the present day. Messrs. A. L. and R. E. Smith have continued work upon a large monograph dealing with the excavations at Uaxactún. Other monographs are in preparation by Dr. Pollock on the architecture of the Puuc region of Yucatán, by Mr. Ruppert on explorations in Campeche, by Mr. Richardson on the antiquities of Honduras, by Mr. Thompson upon excavations in British Honduras and upon a study of prehistoric Middle American deities, and by the Chairman upon the Kaminaljuyu mounds near Guatemala City.

During the year the Institution's field station at Chichen Itzá, occupied since 1923, has been given up and Dr. Morley has established headquarters in the outskirts of Mérida, where space is available for storage of Division equipment and the ceramic collections.

In January President Bush, President Keppel of Carnegie Corporation, Mr. Shepley, Chairman of the Trustees' Committee on the Division of Historical Research, and Dr. Jewett and Senator Walcott of the Institution's Board of Trustees visited Guatemala and Honduras. The work done by the Institution at Quiriguá was inspected, and two days were spent at Mr. Strómsvik's excavations at Copan, where a conference was held with Dr. Rodríguez, Minister of Public Education of Honduras. The party then proceeded to Guatemala City, saw the Division's laboratory there, and made a tour of the highlands to acquaint themselves with the Indian towns being studied by Drs. Redfield and Tax. With Dr. L. H. Adams, Director of the Geophysical Laboratory, and Dr. F. E. Wright a journey was made to the camp on the young volcano, Santiaguito, where Dr. Zies is directing research upon volcanological and magnetic problems. After the return of Drs. Bush, Keppel, and Jewett to the United States, Senator Walcott, Mr. Shepley, and the

Chairman flew to Yucatán and visited Dr. Morley at Chichen Itzá.

Reports upon field and laboratory activities appear below.

COPAN

G. Strómsvik

The work of excavation and repair at the ruins of Copan, Honduras, which has been in progress since 1936 in cooperation with the Government of Honduras, was continued during the past winter. Mr. Strómsvik was assisted by Mr. Frank Lee. The two major activities of the season were completion of the resetting of the great Hieroglyphic Stairway and further investigations of the ball court and the temples adjoining it.

The Hieroglyphic Stairway, perhaps the most imposing single element ever achieved by Maya architects, rose between wide sculptured balustrades to a temple crowning a lofty pyramid. From bottom to top, carved upon the risers of its sixty-two steps, ran a calendrical inscription, the longest so far discovered in the Maya area. When the work of repair was started, the lowermost fifteen steps were still in their original position; fifteen others that had slid downward en bloc almost certainly came from a space beginning twelve steps above. The blocks of stone which had composed the rest lay about the court in front of the stairway, where they had been carried during the course of earlier excavations at Copan.

With the assistance of Dr. Morley, the order of the blocks was worked out as fully as possible, and they have now been replaced in the stairway. This was done not only to restore the stairway to its former magnificence, but also to preserve the inscribed stones from the vandalism and natural deterioration to which they were exposed in the court. Some of the steps are incomplete; a few possess only one or two of their original stones, the others having been either crushed beyond recognition or carried away. But all rebuilt sections are now so marked that the student can distinguish between those elements which surely occupy their correct posi-

tions, those which are probably rightly placed, and those as to which doubt exists. They are also set in such a way that the order of the individual stones can easily be changed in the event that further research indicates errors in the present arrangement.

The stairway was decorated with a central ascending line of human figures, five seated and one reclining. The first seated figure was found in place at the tenth step; many years ago the second, which was at the twentieth step, was, with permission of the Honduranian Government, taken to the Peabody Museum of Harvard University; the third, lying in fragments in the court, has been restored on the thirtieth step; and the reclining figure rests on the thirty-seventh. The fourth seated figure is restored on the forty-fourth, the uppermost on the fifty-fourth. A smaller, standing figure has been placed in the center of the short unsculptured stairway which continued upward from the pyramid's summit platform to the top of the substructure supporting the temple. The latter had long ago collapsed, and the elaborately sculptured stones which ornamented it were found scattered on the flanks of the mound. Its hard lime floor, though much broken by falling rocks and torn apart by tree roots, still remained. The pieces were fitted together and cemented in place to indicate the size and shape of the temple's single chamber.

The stones composing the balustrades of the main stairway, having been relatively small, were badly crushed in the general ruin of the structure; many of them, too, seem to have been carried away for building purposes during the years before the government put a stop to that practice. Such as remained were assembled and reset. "Owl elements," wing-like stones on each of which was carved a conventional owl's head in front view, occurred at intervals of five steps. Being broader than the balustrade, they protruded from its sides.

Excavation, study, and repair of the ball court were continued. It had been determined, during former seasons, that the existing court had been the latest of three such structures which had successively occupied

approximately the same position. During 1940, the plans of the two earlier courts were worked out from such parts of them as had remained buried below the latest one. Of the two temples which had flanked each of them, very little was left. It was determined that the first court had been built on virgin earth and connected with earlier structures to the east and south. The second was built on exactly the same plan as the first, but the floor level was raised about 90 cm. The latest court was raised about 20 cm. above the second and was situated about 6 m. to the north and 2.5 m. to the west, the north end having been swung some 4° west of the axis of the earlier courts, which was about 2° east of true north. This change was apparently made when the latest increment of the pyramid of the Hieroglyphic Stairway was added. All three courts are of the same size, with benches of the same height, width, and pitch of slope. Only the latest court was paved with stone. Hieroglyphic inscriptions and sculpture were found only with the two latest courts. The paving of the playing surface of the third court, which had been much disarranged by tree roots, was relaid in 1938; during the past season both benches were repaired and four large stone parrot heads that had fallen from the benches were replaced, thus completing all six, three on a side. The low vertical walls back of the sloping benches were rebuilt, and the substructures of both flanking temples were reconditioned. The outer walls of the temples were relaid up to the spring of the vault. At two places the stepped vaults of these temples are still in position to within a couple of courses of the capstones, but these must be consolidated before long, to prevent collapse and loss of this important evidence of vault construction.

Minor activities during the past season included the repair and re-erection of Stela and Altar 13, the raising and blocking-up of Altar 14, and the re-erection of the uncarved stela of this altar. For its better preservation, Stela 6 was also repaired and re-erected. The perplexing problem of how the Court of the Hieroglyphic Stairway was drained was

solved: a drain 65 cm. deep by 70 cm. wide was found entering under the west end of Mound 11, starting about 20 m. west of Stela N and running southward under the Acropolis; the outlet could not be found. A small tomb with a badly decayed skeleton was found in the north end of Mound 7; two of the accompanying vessels may be of southern origin, and the third is of plumbate ware, which may indicate that the burial dates from after the close of the Old Empire. The most striking single find of the season was the gigantic and well preserved human head, carved in stone, at the northeast corner of Temple 11. It is 85 cm. high and is part of an enormous human figure which adorned the northeast corner of the temple; the hands and feet had been found years ago. There is another much-broken head which belonged to a similar figure at the temple's northwest corner.

Mr. Shook spent six weeks at Copan, making a detailed study and section of the north half of the river-cut face of the Acropolis, with minor excavations to determine the lowest building levels. He also excavated a glyptic panel at the east end of Temple 11. This is the eighth panel of this type found in that temple, but the only one with its complete text in good preservation. During his stay, Mr. Shook added to the master map of the Main Group all data which had accrued since 1937.

THE ARCHITECTURAL SURVEY OF YUCATÁN

H. E. D. Pollock

Brief reports upon the purposes and progress of the Architectural Survey have appeared in earlier Year Books (No. 30, pp. 117-119; No. 31, pp. 96-97; No. 34, pp. 124-126; No. 35, pp. 122-125; No. 36, pp. 141-143). It has been pointed out that the so-called Puuc region of Yucatán saw the initial efforts of the survey, and by the close of the 1936 season it appeared that that area had been sampled adequately. During these years occasion had been taken also to reconnoiter the Chenes region to the south and to make brief trips into the Maxcanú, Hecelchakan, and Campeche districts to the west

and southwest. These last-mentioned districts, although relatively populous and easily accessible, form an area that has been a notable blank spot on the archaeological map; yet the information gained by these trips suggested not only that the region possessed numerous remains, but that these remains were closely allied to, if not merely a variant of, those of the Puuc. The three comparatively well known sites in the area, moreover, appeared in each case to be of strategic importance. With the survey of the Puuc ruins completed and the Chenes ruins sufficiently sampled to give a good idea of what was to be expected in that region, it seemed logical to extend the work to this western area that appeared to have so definite a bearing upon the architecture of the Puuc.

Preparatory to entering an area whose ruins were virtually unknown, it was deemed advisable to conduct some preliminary exploration. During the preceding winter (1939) two native laborers, trained in the work of the survey, were consequently sent to this region to locate and briefly describe new ruins. The results were even better than anticipated. At very small cost these men visited and reported upon some twenty-five previously unrecorded groups. The Architectural Survey was thus able to enter the field the following year with a long list of partially explored sites, and with valuable and time-saving information on such matters as facilities of transportation, water supply, and living conditions.

The 1940 expedition consisted of Dr. Pollock and Mr. Shook. The broad plan of operation was to start at Maxcanu, the northern tip of the area to be covered, and to work southward along the Campeche railroad line, constantly striking eastward into the interior hill region and occasionally ranging westward onto the coastal plain. In an earlier year the ruins of Oxkintok, just outside of Maxcanu, had been briefly visited and marked as large and of strategic importance, an opinion that was confirmed in 1939 by the discovery of a lintel carrying the earliest Initial Series date (9.2.0.0.0) so far known in northern Yucatán. Work was therefore be-

gun at that site and was continued for about one month, a large number of outlying groups and two small near-by sites being explored as well as the centrally located ruins.

The ruins of Oxkintok are characterized by two types of building that seem to represent different periods of occupation. What are assumed to be the remains of the earlier period are akin to certain southern Maya ruins in assemblage, style of architecture, details of construction, and the association of monuments with hieroglyphic inscriptions. The early Initial Series lintel mentioned above is *in situ* in a structure of this style of architecture. The second class of building, assumed to be later, is of typical Puuc tradition. In general, the earlier remains tend to cluster in the central part of the site, and the outlying groups and a certain number of structures near the center are for the most part in Puuc tradition. These explorations disclosed some notable examples of stone sculpture and a considerable body of hieroglyphic material as yet not studied.

The second part of the season's work, again amounting to about one month, was concentrated in the Cumpich-Xculoc-Halal region, east of the railroad station of Hecelchakan. Some twenty sites, varying widely in size and importance, were visited. Broadly speaking, the remains of the region are akin to the previously studied ruins in the savanna of Xcalumkin. They are very similar to the buildings of the Puuc but, in Dr. Pollock's opinion, are distinctive in a sufficient number of details to justify their being set apart from the ruins of that area. As at Oxkintok, a considerable amount of hieroglyphic material and stone sculpture was discovered, and in addition some fragmentary examples of wall fresco were found.

The third and last part of the 1940 season was devoted to exploration of the region along the railroad and east of the railroad between the towns of Pomuch and Hampol. Here again some twenty sites were visited, and in the main it may be said that the remains are in the same tradition as those of the area surveyed on the preceding trip. Possible exceptions are the ruins of Bakna,

northeast of Bohola, where there appear to be traces of the early-style architecture of Oxkintok; and Acanmul, near Hampolol, where assemblage and relatively high proportion of pyramidal-type structures set the ruins off from those of the major part of the region. During the final week the site of Oxkintok was revisited to check up on certain matters considered important, and at the same time the ruins of Sihó, west of Halacho, were visited. These last ruins, while in certain respects akin to those east of the railroad, are in other ways distinct. Upon returning to Mérida, a brief visit was made to the long-known, but so far inadequately studied, ruins of Acanceh and Mayapan. It should possibly be noted here that the Acanceh remains are strikingly similar to relatively early southern ruins.

The work of the past season has been one more step in clarifying the cultural picture of northern Yucatán. Not only have a large number of ruins been examined in an area that was relatively unknown, but that area is found to have a concentration of remains comparable to that of the Puuc region. The main concentration appears to lie in the hill and savanna region east of the railroad, the railroad towns, mostly old aboriginal settlements, forming the western border at the foot of the hills. The coastal plain west of the railroad gives evidence of a comparatively sparse aboriginal population. From the point of view of architecture, the area is extraordinarily homogeneous. As noted above, the remains are so closely akin to those of the Puuc as to present the question whether they should be differentiated at all. There is little that occurs in the region that might not be found in the Puuc; but Dr. Pollock believes that the proportion of certain forms of assemblage, types of buildings, ground plans, structural details, decoration, and glyptic material justifies distinguishing these remains from those of the Puuc. Departing from the general architectural homogeneity of the region are the presumably early remains of Oxkintok, which represent a cultural horizon that may be present at Bakna but as yet finds no direct parallel elsewhere. Acanmul and

Sihó also give signs of divergence from the norm. The source and cause of these divergences are at present unknown.

Future objectives of the Architectural Survey seem clearly to lie to the south in the region extending east from the Campeche-Champoton coastal strip. The work of the survey to date has given good indications of the borders of the Puuc and of this new subcultural area in its northern sector, but its southern limits have not been defined, nor has the expected Chenes border been discovered. An extension of the survey south and southeast should solve these problems. In addition, there is hope of picking up further traces of the early Oxkintok architecture. In the past it has been the experience of the survey that major advances in the understanding of the broad cultural picture have come in passing from one cultural area to another, and it is confidently expected that the delimiting of this new area to the south and southeast, and the knowledge of what type of remains are contiguous, will greatly clarify the relation of these remains to those of the Puuc and Chenes. There are, moreover, the broader questions of the entrance and continuing flow of culture to Yucatán from the south and west, and the region suggested for future work appears to hold promise of throwing light upon such problems.

EXPLORATION IN SOUTHWESTERN CAMPECHE, TABASCO, AND THE DEPARTMENT OF PETÉN

E. Wyllis Andrews

In the course of decades of exploration and excavation, a large part of the Maya area has become intimately known to the archaeologist. Up to the present decade, however, work has been concentrated at the northern tip of the Yucatán Peninsula (the "New Empire" area) and at the opposite end in northern Honduras and the lowlands of Guatemala (the "Old Empire" area). In the course of these investigations the intervening country was almost completely ignored, but recently the work of Messrs. Pollock and Ruppert has gone far to bridge the archaeological gap between these

two regions. Dr. Pollock has conducted an architectural reconnaissance of the Puuc and Chenes areas in the north. Mr. Ruppert on his several Campeche expeditions has explored the western part of southern Quintana Roo and the eastern part of southern Campeche. A large gap still remained, including that part of Campeche south of Champoton and west of La Tuxpena, the part of Tabasco north of the Usumacintla River, and the northwestern corner of the department of Petén in Guatemala.

During the past winter, Mr. Andrews spent several months in a preliminary exploration of this territory. He was accompanied by Mr. Melvin A. Traylor, of Chicago, who, establishing himself at several base camps during the period, made an extensive collection of birds for the Field Museum of Natural History.

The party left Mérida in the middle of December, proceeding directly to Matamoros, Campeche, where by the courtesy of Mr. Cecil L. H. Branson, of the Laguna Corporation, Mr. Andrews was able to make a trip northward to a group of ruins reported near the chicle camp of Carrizal, then in a large circle to Mocu, Cilvituk, Konhuas, and Esperanza, whence he was able to fly by chicle plane back to Matamoros. Except at Carrizal and Cilvituk, no standing remains were encountered. However, the entire area was covered with concentrated groups of mounds in complete ruin, many of them (such as those at Mocu) of considerable size and extent. An extremely dense population in ancient times was clearly indicated. At Carrizal, the only fragment of standing architecture contained a vault very reminiscent of Tzibanche in its extreme narrowness and "cupola" shape.

Interesting remains were noted on an island in the center of the Laguna Cilvituk, previously visited by Maler in 1895. Two sites were named Isla Cilvituk A and B, to distinguish them from the large remains on the mainland near the village of Cilvituk. In one of these groups was a low substructure with a square temple with flat beam-and-mortar roof.

From Matamoros, an excursion was made to the village of Pustunich, 100 km. south of

Campeche near the line of the Ferrocarril del Sureste. Here two sculptured monuments were found which almost perfectly duplicate the style of the sculptural material found in 1937 at Telantunich in Quintana Roo. The resemblance was so startling that these new sculptures may safely be classed as organically related members of the complex defined in Mr. Andrews' paper on that area. One of these, a grotesquely phallic male statue, had been re-erected in a shrine for local worship. Under the name of Santo Pus, he is now the center of the village's Catholic ceremonial.

Returning to Matamoros, the party then flew to Pacaitun on the Río Candelaria for a reconnaissance of this drainage system. Excursions were made to the mouth of the river, and then upstream to the heads of its two main tributaries, the Río San Pedro and the Arroyo Caribe. From Laguneta at the head of the Caribe, a trip was made to the chicle central of Aguada Seca to the east. In this entire area no standing ruins were encountered, but the examination was sufficiently exhaustive to permit the conclusion that probably no large remains of this sort will be found here in the future. As in the Matamoros region, however, wherever the terrain was habitable, large and small mound aggregations were found in surprising density—again indicating an unusually dense population in ancient times. Pottery was to be found almost everywhere on the ground, and notes were kept of specific deposits and stratifications to aid in future ceramic study of this region.

Finally, Mr. Andrews made a trip to the south, crossing from the Río Candelaria to the Río San Pedro Martir, and on to Tenosique on the Usumacintla. In the course of a brief visit to Piedras Negras and Yaxchilan, a previously unphotographed fragment of Stela 38 at the former site was encountered. This fragment bears the terminal date of the monument, 9.12.10.0.0 9 Ahau 18 Zotz. Connected to this by a secondary series is the further date 9.12.6.5.9 4 Muluc 7 Zac. The assembly of the fragments of this monument in *The inscriptions of Peten* apparently

includes an eroded fragment which was not part of the stela.

Information was obtained at Balancán regarding a large site one day's journey up the Río San Pedro Martir, and a visit was made possible through the kindness of Don Pablo Ocampo, on whose lands it was located. Maler had heard of this ruin in 1907, and named it La Reforma III, although he did not visit it. As the settlement of Moral is considerably nearer the ruins than the *finca* of La Reforma, and as Reforma is a confusingly common name throughout this general region, the former name has been given to the ruins. Moral was a very large city, extending in compact plaza groups over several square kilometers. Although many of the mounds are extremely high, no standing remnants of architecture were found. This was partly due to the ravages of time and weather and partly to the fact that many of the larger pyramids had been completely stripped in recent times to fill gullies on the road detouring the two leagues of unnavigable water between La Provincia and Palomillo on the nearby San Pedro. In one of the plazas of the city were found a sculptured stela, a plain stela, and a plain round altar. The stela was carved on four sides, the front and back with human figures, the sides with hieroglyphic dates. Above the standing figure on the back of the monument was a well preserved Initial and Supplementary Series, dating it at 9.16.5.0.0 8 Ahau 8 Zotz. The style of the monument is unmistakably that of the Petén, in contrast with that of the nearer cities of Yaxchilan and Piedras Negras on the Usumacinta and Palenque to the south. This indicates that the Río San Pedro was an artery of cultural traffic in middle Old Empire times.

Mr. Andrews returned by river to Carmen, whence he flew over the lower Chumpam and Candelaria drainages to Pacaitun. He returned to Mérida early in March.

INVESTIGATIONS IN GUATEMALA

A. L. Smith and E. M. Shook

Since the close of the Institution's excavations at the ruins of Uaxactun, in the depart-

ment of Petén, the place has been made a center for the collection of chicle and a landing field has been established for its shipment to the coast by air. Taking advantage of its new accessibility, Mr. Smith and Mr. Shook flew to Uaxactun in January and devoted a week to minor excavations and observations needed to supplement the data gathered during the original study of the ruins. The digging was for the most part in search of potsherds which would serve to place in their proper chronological position various deposits, buildings, and parts of buildings whose periods had not previously been determined with certainty, but which, during the writing of the final report upon Uaxactun, had been found to be of special significance. In this way the elaborate Structure E-VII sub and Temple B-XIII were assigned to the Chicanel and Tzacol phases respectively. Observations were also made on the ball court, and upon several stelae.

After Mr. Shook left to join Dr. Pollock in Yucatán, Mr. Smith proceeded to San Agustín Acasaguastlan, in the valley of the Motagua River, to conduct excavations and to explore the hitherto little-known remains in that region.

In 1935, a brief visit to San Agustín by Drs. Kidder and Ricketson had indicated that there were many tombs at the site and that the local culture differed in various ways from that of other Maya centers. Assisted by Dr. Gustavo Espinoza, Mr. Smith spent two months at San Agustín. His original plan called for two weeks of excavation and six of exploration. The mounds investigated proved, however, so interesting and so rich in archaeological valuable specimens that the greater part of the season was devoted to them. During this time a ten-room structure, which had perhaps been vaulted, was cleared; a ball court and a small temple were studied; and numerous pits and trenches were dug for the recovery of potsherds. The most important finds were made in a mound which held two tombs. These were of the slab-vaulted type known to exist at San Agustín but not previously examined by competent archaeologists. The vaults were rectangular cham-

bers into each of which led an entrance passage sealed with large stone slabs. They appeared to have been kept in use for mortuary purposes for a considerable time, as each of the two held remains of many individuals, the bones of the earlier interments having been disarranged and pushed aside for later burials. From the vaults were taken a large number of pottery vessels of various types, some of them of a beautiful red, black, and yellow on cream polychrome ware which has not hitherto been reported.

Preliminary study of the vessels from the tombs and the sherds from the general digging indicates that at least two ceramic periods are represented at San Agustín: one approximately contemporaneous with, but easily distinguishable from, the early Old Empire Tzacol phase of Uaxactún; the other somewhat later than the terminal Tepeu phase of the latter site. Plumbate ware, so far not found at Uaxactún, and believed to date from the very end of the Old Empire, was in use during the time represented by at least the latest of the tomb burials.

Among the sherds are specimens which seem surely to be of nonlocal manufacture. Some of these are of wares characteristic of the Petén, others of Copán, and still others of the Guatemalan highlands. Owing, however, to the considerable time during which the tombs were in use, and to the extraordinary amount of building and rebuilding that took place at San Agustín, there seems to be a certain amount of mixing of materials of different periods. For this reason the sherd collections now at hand are not of maximum usefulness for determining the exact chronological relations of the two postulated San Agustín periods with the ceramic phases of other culture areas in the Maya field. It is nevertheless probable that further excavation specially directed toward that end would result in location of undisturbed and therefore pure deposits.

At the close of his excavations, Mr. Smith explored and mapped the Motagua valley and the lower courses of its tributaries for a distance of about 50 km. from Zacapa to Progreso, finding many ancient sites in which

were noted no less than sixteen hundred mounds of characteristic San Agustín type. Most of these are undisturbed. He also found ruins at a greater altitude near El Rancho which seem to represent a different culture. Their structures bear analogies to those of Rabinal.

STUDY OF YUCATECAN POTTERY

George W. Brainerd

The purpose of the study now under way is the establishment of a correlated sequence of the prehistoric pottery types of Yucatán in order to discover what chronological and cultural interrelations existed among the archaeological sites.

Such a chronological scale is, of course, of prime importance in providing the historical framework to which the archaeology of any area must be fitted. Although Maya epigraphy has furnished us with the basis of our chronology, the absolute dates thus obtained can necessarily serve only as anchoring points for a detailed cultural history. Many Yucatecan sites have no dated monuments, and when sculptured dates do occur the difficulty of associating them closely with structures and artifacts is often insurmountable. Pottery provides the easiest and most reliable method available for the exact placing of cultural material in the time scale.

It is probable that a careful study of Yucatecan pottery will uncover data of much more general significance in Maya archaeology than the simple filling-in of dates on a calendar outlined by epigraphic evidence. Although Yucatán is peripheral to the main Central American cultural stream, the importance of its chronology is enhanced by the fact that the correlation between the Christian and Maya calendars (upon which all exact Maya datings depend) is based upon Spanish records made in Yucatán at the time of the conquest. Owing to the abbreviated method of writing dates used by the later Yucatecan Maya, there is a period of unknown length between the last inscriptions written in the unabbreviated older style and the date of the conquest. Therefore, a pottery chronology

correlated with the abbreviated hieroglyphic dates, reaching from the conquest to any of the Old Empire style dates, is needed.

The materials available for the study consist of pottery collections from some thirty sites in the Yucatán Peninsula which have been made by various Carnegie Institution workers during the past sixteen years. They consist of a few whole vessels, and about 100,000 sherds selected from excavated collections of perhaps eight times that number of fragments. The bulk of the pottery comes from the extensive excavations carried on at Chichen Itzá. Most of this material was obtained as a by-product of the excavation and restoration of buildings, although some was taken from special trenches cut into dumps. Test samples from most of the other sites represented were obtained by H. B. Roberts during four field seasons, spent chiefly in the Puuc region in the western part of the peninsula, in conjunction with the architectural survey of this region conducted by H. E. D. Pollock. This joint survey was arranged in the hope that the cross-correlation of architectural and ceramic traits would give a rounded picture of the sites visited. The pottery survey was, however, interrupted by the illness and subsequent resignation of Mr. Roberts.

Dr. George C. Vaillant formed some tentative theories as to Yucatecan pottery chronology in 1927 from a study of the whole vessels available in museums, and in 1929 he worked out a partial Chichen Itzá chronology from trenches in the court of the Temple of the Phalli. At Holmul (which actually does not belong in this region) a pottery sequence was determined, chiefly however from ornate burial pottery which cannot be correlated with the pottery normally found in excavation. Other than these isolated studies, no chronological pottery work has been reported upon.

The following sites were represented in the Carnegie collections stored at Chichen Itzá: Calakmul, Coba, Holactun, Oxkintok, Uxmal, Chacbalai, Chacmultun, Chunhuhub, Dzibilnocac, Dzibiltun, Chichen Itzá, El Palmar, Labna, Santa Rosa Xtampak, Yaxuna,

Kabah, Kewic, Muluch-Tsekal, Nohcacab, Nocuchich, Hochob, Huntichmul, Iturbide, Itzimte, Sabacche, Sayil, Tabasqueno, Xlabpak-Maler.

Dr. Brainerd began this work without previous experience with Central American pottery, but with archaeological experience in Iran, northern Arizona, and Tennessee, and a total of about three years' intensive laboratory work on Arizona pottery carried on for the most part at the Ceramic School of the Ohio State University. Therefore, although methods of dating by means of potsherds were well known to him, a period of study of the new type of material was felt necessary. At the beginning of this project in December 1939, six weeks were spent at the laboratory of Miss A. O. Shepard in sorting and microscopic examination of sample collections of Yucatecan shard material.

After this work and after study of Roberts' field notes, Dr. Brainerd went to Chichen Itzá to begin detailed study of the collections. The work in Yucatán has thus far consisted almost entirely of classification and description—the building-up of the corpus from which the results will be drawn. A week was spent in excavating pottery samples, totaling several thousand sherds, at Oxkintok, where an early date had recently been discovered. Three weeks were spent with Mr. R. E. Smith in the location of Petén types of pottery in the collection, and in the discussion of methods for Maya pottery classification. Owing to the deterioration of labels caused by four years' dead storage in so humid a climate, considerable reorganization and relabeling was necessary. To minimize further deterioration, and to prevent confusion in the extensive sherd comparisons now being made, the majority of the sherds have been printed individually with their provenience. The collection has also been indexed and moved to Mérida, where it is now permanently housed. During the time consumed by the move, 600 photographs of pottery were taken in private and museum collections at Mérida, for the purpose of comparison and as an aid to the reconstruction of whole vessels from the sherds in the Carnegie collection.

Although the study has not reached the stage of interpretation, a tentative statement of the developments as they now appear may be made.

The work was begun on material from Coba, and continued with that from Yaxuna, Calakmul, and various Puuc sites, on the theory that the best understanding could be reached by following a sequence from early to late, based on available site datings. Chichen Itzá was left until last. Its location is somewhat isolated, making it not essential to the Puuc chronology, and it was felt that its comparative complexity could be better unraveled if the chronologies of related regions were built up first.

The Coba sherds were easily divided into two groups: one of finely made and quite varied pottery; the other all made of a very coarse calcite-tempered paste, some pieces slipped and some unslipped. In the deepest trench the fine ware is much more common at the bottom of the deposit, which seems to have antedated the plaza floor upon which the near-by buildings stand. According to Mr. Smith, who examined the pottery, the fine ware is in large part analogous with Old Empire wares found at Uaxactun. The coarse ware bears a general resemblance to the San José pottery illustrated by Thompson, although there are minor, constant differences. Interestingly enough, there are only 27 fragments of the slateware so abundant in many other Yucatecan sites. These were scattered through the tabulated sample of 2338 sherds—about 1 per cent. The two possible explanations of this scarcity are that the Coba deposit in question precedes the body of Yucatecan sites, and that slateware was not made in or often traded to that part of the peninsula. Fifteen sherds containing a considerable proportion of finely divided cellular material, seemingly plant stalks, were found well scattered through the trenches. They all came from similarly shaped vessels. Miss Shepard, to whom a sample was sent, reports that she has not examined pottery similar to this. The presence of a type of temper differing so widely from the mineral tempers characteristic of the Maya area suggests the possibility

of foreign cultural contacts on the east coast of the peninsula.

The collection from Yaxuna is very small (272 sherds). Since no qualitative differences could be seen in the sherds, they were tabulated together. Over 50 per cent of the material consists of slateware, a proportion close to that found in the Puuc material so far examined, although the shapes are somewhat different. There are two types of coarse, unslipped, calcite-tempered jar rims, one of which is more suggestive of the corresponding material from Calakmul than of that from any other site in the collection. Mr. Smith classifies several of these rims as of early Old Empire Petén types. Red-slipped, coarse ware is present in Yaxuna as at Coba, but in smaller proportion. Fine, thin-walled monochrome and polychrome wares, markedly different from the above material, constitute about 15 per cent of the sherds. Smith identified various sherds from the Yaxuna series as belonging to pre-Old Empire and Old Empire Petén types, but the present collection is too small and mixed to allow of its correlation by individual samples with the distinct Yucatecan wares present. More excavation is obviously required to clarify this situation. The results might well justify such excavation. The large time range represented by the relatively abundant Petén-style material should give valuable checks of the sort needed for correlations with epigraphic material if pottery deposits of sufficient size can be located.

A collection from Calakmul was examined and tabulated. It had been gathered during work upon stelae, and came from the fill which had fallen against the monuments as a result of the collapse of adjacent structures. Hence the suggestion is that the pottery is older than the stelae, although this may not be so. Smith classified most of this pottery as late Old Empire, and considers it to vary only slightly from Uaxactun material. A large proportion of the slips on coarser vessels from Calakmul shows the translucency and waxiness of the slips of slateware, which is present in very small percentages, if at all, at Uaxactun. Their colors are generally deeper

than the dull buff or gray most common in Yucatecan pottery. It seems possible that there may be some intergrading of slateware with Petén types.

The material from Oxkintok, where an almost certainly early date (9.2.0.0.0) has been found, was excavated in the hope that early pottery from the Puuc area would be forthcoming. Fortunately there was found a deposit 2.5 m. deep containing a seemingly homogeneous mass of pottery overlaid by nearly sterile earth. In the top of this trench, as well as in three others, pottery comparing closely with that from other Puuc sites was found. The earlier pottery includes no slateware, and it is in other ways quite different from any other in the Yucatán collections. Mr. Smith was also unable to place it. Much of it has a slip averaging light ochraceous buff to cinnamon, applied over a slightly granular surface. The vessel shapes are highly diagnostic; one of them, a basin with sub-rim flange, is reminiscent of the coarse, red-slipped basins of Coba, as is the general scale and texture of the whole ware. It seems likely that the affiliations of this pottery will be found in early sites somewhere to the southwest of the peninsula. At present there are no such sherds for comparison.

In the Kabah collections Mr. Smith found sherds which he equates with nearly the whole range of Uaxactun ceramics. He also noted slateware in shapes characteristic of Uaxactun. These findings, of course, suggest a long occupational sequence which might be tied in with the Petén. Unfortunately a listing of his identified sherds shows them to be distributed so haphazardly through trenches and levels that a chronological rating of the trenches is impossible. The local wares also have not suggested any stratigraphy as yet, although a complete tabulation was made for all trenches. The sample is rather small (1244 sherds); more excavation might help in the correlation, particularly if large, homogeneous deposits could be found.

The collections from Uxmal are large and contain material of a very high grade. Their homogeneity, as well as their lack of Petén resemblances, suggests an extensive and late

occupation. The larger collections from the site have been tabulated and several show good stratigraphy, although the changes are in percentages of types rather than in the types themselves. The lower levels of several of the trenches at Uxmal yield specimens corresponding closely to materials from Kabah, while the upper levels do not. More definite comparisons between the tabulations should allow closer correlation between the two sites.

It seems evident from the Puuc materials examined that few definite qualitative criteria exist between sites, and that correlations and datings must depend upon close statistical work and perhaps upon mineralogic differences between potteries made at different sites.

The Chichen Itzá pottery has not yet been tabulated, although considerable time has been spent in its organization. From cursory examination it seems evident that for the most part it is quite distinct from the pottery thus far worked. The determination of its chronology should be considerably helped by the architectural evidence accompanying the pottery, by the large size of the samples, and by the system evolved during the handling of the other collections.

The above observations have been made previous to a general, systematic comparison of all the material. Later work may confirm or refute them, and will indubitably add others. The final goal of the study, a chronological scale, can be reached of course only upon the close intercorrelation of all material, which will be the final step of the present work.

At present the establishment of a Puuc chronology seems certain, although the number of stages and dating criteria which it will comprise is not yet evident. Owing to Mr. Smith's examination of the collection, we now know that a considerable quantity of Petén-style pottery is present, and it is possible that technological analysis will prove whether such pottery is imported or locally made. The presence of early Petén pottery in the badly mixed deposits dug at Kabah suggests that more excavation might yield material for the Old Empire chronological

check mentioned on page 270. The newly discovered complex at Oxkintok, of which we have a large sample, may prove to be the first step in the discovery of the time and route of Maya colonization in western Yucatán.

The pottery of Coba substantiates the epigraphic and architectural evidence of its Old Empire and east-coast affiliations, and suggests that further work might produce Puuc dating correlations. The samples from Yaxuna indicate a much closer connection with the Puuc than with Coba, although a moderate percentage of Coba material is present. Actually, Yaxuna is closer to Puuc sites than to Coba, a fact which the presence of the Coba-Yaxuna causeway has tended to obscure. The finding of early Uaxactun-like pottery adds another argument for further excavation at Yaxuna, in the hope of closer Old Empire chronological correlations. There is every evidence that Kabah would also yield material interlocking with a long period of Petén chronology, and the size and condition of the ruin perhaps make it a better possibility than Yaxuna for obtaining such material.

Chichen Itzá remains as the likely source of much information which still eludes us. Its long occupation coupled with its median position in the peninsula should allow it to serve as a connecting link among the various isolated samples from widely separated sites. The collections are large, and the material varies widely. The results should be rich.

SOUTHWESTERN ARCHAEOLOGY

E. H. Morris

Investigations in the Anasazi, or Basket Maker-Pueblo, archaeological area of southwestern United States continued to claim the attention of Mr. E. H. Morris. Anasazi culture and its problems were characterized in some detail in the Year Book report for 1938-1939. This report also described a cave near Durango, Colorado, excavated in 1938, which had been occupied so early in the Anasazi cycle that, although its inhabitants cultivated corn and pumpkins, they were still ignorant of pottery, used the spear thrower instead of the bow, and had no hafted axes or hammers. The cave yielded a fair quantity of charred

wood which thus far it has not been possible to date by the Douglass method.

Field work in 1939 was continued through later June, July, and August. Its objective was to open sites inhabited somewhat more recently than the cave, for the double purpose of ascertaining the range and degree of change in material culture which had taken place meanwhile and of obtaining charred wood that might provide a ring pattern that would connect with wood from the cave. On a hummocky glaciated terrain some 5 km. north of the cave, sites in the open abound. The identifying feature of each is a shallow depression 3 to 10 m. in diameter, marking the position of a subterranean room. Such sites obviously are more recent than the cave occupation, but how much, it was impossible to judge before excavation. Four of the underground chambers were cleared. Though each differed from the others in minor details, all were sufficiently alike to permit a generalized description of the dwelling room of the times. It was roughly circular, 4 to 10 m. in diameter, and was sunk 1.5 to 2 m. into the earth. In most cases, but not invariably, there was an encircling bench at about half the depth of the pit. Roof supports were four or six stout vertical timbers, set flush with the face of the bench, or in floor sockets just within the periphery. On the tops of these rested horizontal logs which bore the closely laid poles of the roof itself. Wall poles sloped from the back of the bench, if there was one, or from the margin of the pit, if the bench was absent, to rest their tips against the elevated horizontals. Over the timbers of wall and roof was a layer of reeds, twigs, or grass, then a thick shell of mud. A firepit occupied the center of the floor, and in the southeast quadrant there was a tunnel entrance.

Earth dug from the subterranean room was spread over a circular area surrounding it. Usually a row of stones was laid to mark the rim of the circle. In the northeast arc a few pole-and-mud storage places were constructed, and in an occasional instance these were large and substantial enough to be called above-ground rooms.

Crude pottery, and evidence of bow and

arrows, hafted axes, and hammers were present in the pit rooms. Such innovations, together with the radical difference in house construction, suggested that the sites studied in 1939 were occupied several centuries after the cave had been abandoned. Tentative dating of timbers from them in the middle 700's tends to confirm this opinion. If correct, these dates show that the people of the particular locality had not advanced as rapidly in architecture and ceramics as had their contemporaries in neighboring districts.

Though instructive and important in themselves, the results of the 1939 excavations failed to establish the desired cultural and chronological succession from the cave to sites in the open. However, on a hillside in the

same general locality were found remains that, to judge from surface indications, more closely parallel those in the cave, hence may be expected to clear the problems which the work in 1939 failed to solve. It is planned to open some of the hillside sites in 1940.

September, October, and November were spent by Mr. Morris reading proof on *Archaeological studies in the La Plata district: southwestern Colorado and northwestern New Mexico*, which came from the press December 30. December and the early months of 1940 he devoted to repair and study of specimens exhumed in 1939 and to carrying toward completion a report on Anasazi basketry. On May 13 he returned to Durango to resume field work.

CERAMIC TECHNOLOGY

Anna O. Shepard

Systematic work on the microchemical analysis of ceramic materials was undertaken during the current year for the first time. The desirability of obtaining chemical analyses, quantitative as well as qualitative, of paints and glazes, and also of certain classes of slips and tempering materials, has been recognized from the start, but this field has been neglected partly because of the extreme limitation in quantity of material obtainable, which greatly increases the difficulty of analysis, and partly because results of petrographic analysis have proved so fruitful that full time has been required for meeting the archaeologists' demands. Therefore only a relatively few simple qualitative microchemical tests have been used. During the past year a part-time student assistant handled routine work required for petrographic analysis, freeing more time for basic research on new methods.

The application of chemical methods in pottery analysis requires much more preliminary experimentation than does the use of petrographic methods. We can use with very little modification the techniques which the geologist has employed for many years, whereas in the case of chemical analysis we

are borrowing from the relatively new but very rich field of microanalysis, and our samples and requirements differ from those for which the methods were developed, so that each procedure must be thoroughly tested and often considerably modified. Quantitative determinations on samples as small as those which are obtainable from the pigments of pottery present such serious difficulty that until recently they have rarely been attempted by the chemist. Our laboratory is equipped with a microbalance (weighing to 0.000002 g.), without which quantitative work would be impossible, a photoelectric colorimeter, and a microelectrolytic apparatus, all of which greatly facilitate the work. During the summer of 1939 the assistance of Mr. F. G. Schoffman, of the Chemistry Department of the University of Colorado, was obtained, and methods for quantitative determination on 3-mg. samples of eight of the elements most commonly found in ceramic materials were tested and applied. Gravimetric, volumetric, electrolytic, and colorimetric methods were used. In this preliminary work, in order to test the methods and also to test the value of the chemical data from the archaeologists' point of view,

samples of twenty-eight Pueblo glaze paints were analyzed quantitatively for from two to eight elements. Glaze paints were selected for analysis because the geographic distribution and sequence of types is sufficiently well known to permit the formulation of specific questions regarding trade, and direct influence on, and independent developments in, technique. Comparable material is not available at present from the Maya area. The results showed, first, that it is possible and practicable to make quantitative determination on 3-mg. samples with an accuracy well within the limits required by the nature of our materials; second, that the results of such analyses have archaeological significance and enable us to answer directly questions which would otherwise remain subjects of speculation; third, that quantitative as well as qualitative analysis is necessary satisfactorily to answer these questions.

During the fall and spring microchemical work was continued with the analysis of three classes of Maya ceramic materials: iron manganese paint, carbonate tempers, and clay slips. Quantitative determinations of iron and manganese were made on the paints by rapid colorimetric methods to learn whether or not the ratio of the two major constituents might distinguish ores from different deposits. The painted wares on which this kind of pigment occurs are as yet ill defined, and little is known of their origin and relationships. Similarities or differences in paint should help clarify these questions. The quantitative methods developed are rapid and accurate, and preliminary results showed a wide variation in ratios, and some indication of correlation with pottery types.

The carbonate tempers were studied in order to find a simple field test to distinguish dolomite or dolomitic limestone from magnesium-free limestone. Carbonate tempers were used in such a large proportion of Petén pottery that it is desirable to distinguish varieties of this temper in order to use temper as a means of locating sources or distinguishing wares from different sources. So far dolomite and dolomitic limestone have been found in distinctive pottery types, but we

have lacked a satisfactory field method for rapid identification of dolomite. Four organic reagents for magnesium were studied and their sensitivity and the limiting proportions of interfering ions were tested. One reagent, Titan Yellow, was found satisfactory for field use.

A number of Maya pottery types are characterized by slips having peculiar properties; for example, the exceptional luster and brightness of color of Petén orange and red ware, and the hardness, vitreous appearance, and iridescence of plumbate ware. It was thought that chemical analysis of major constituents, particularly silica, alumina, and iron, might indicate whether or not an unusual type of clay was used, and aid in explaining these properties. The composition of the surface material of plumbate, an important ware in Middle America because of its wide distribution and definite chronological position, was of particular interest because it was not definitely known that the surface had a clay slip, and the nature of this surface has long been a puzzle to archaeologists. The microquantitative determination of silica in 3-mg. samples proved difficult, and a number of procedures were tested before satisfactory results were finally obtained by using a platinum filter stick to avoid transfers. Three Petén samples and seven from plumbate and plumbate-like sherds were analyzed. The results showed that plumbate ware has a slip of claylike material, and the proportion of elements determined sheds light on the peculiar properties of the surface.

Opportunity was afforded through a special grant to test the applicability and value of spectrographic analysis of the materials which were being tested microchemically. We were especially fortunate to have the analyses made at Massachusetts Institute of Technology under the direction of Dr. G. R. Harrison. Two hundred and six samples were analyzed, including glaze paints, iron manganese paints, clay slips, and miscellaneous pigments from Kaminaljuyu. Results proved the value of the method for rapid qualitative identification and especially for the detection of trace elements which could not be identified by any

other means. Trace elements no less than the ratios of major constituents may serve to distinguish material by source. Encouraging results were obtained with the Petén slips, but in the Pueblo glaze paints the proportion of major constituents appears more significant than the trace elements. Some quantitative spectrographic determinations were made of iron manganese ratios, but considerable research will be necessary before this procedure can be generally applied.

The collection of samples no less than the method of analysis presents serious problems. From one to two hours were required to obtain by delicate scraping most of the samples analyzed. The process must be observed with the binocular microscope to avoid inclusion of clay with the paint, and the risk of contamination is too great to intrust the work to an assistant.

During the fall approximately a month was spent in a final check of pottery from Benque Viejo, British Honduras, for Mr. Thompson's report on this site. From November through early January laboratory facilities were made available to Dr. G. W. Brainerd, and assistance was given him in his preparation for work on Yucatecan pottery.

Petrographic studies were facilitated by the part-time assistance, from October through the rest of the year, of Mr. R. Spangler, senior in geology at the University of Colorado. Mr. Spangler, after training, prepared 674 thin sections. Sherds from Uaxactun, Zacualpa, Kaminaljuyu, Miraflores, and San Agustín were sectioned. Mr. Spangler was also trained in the use of the binocular microscope for temper identification, and identified temper

in a large collection of stratigraphic test sherds from a Rio Grande site, lent through the courtesy of the Museum of New Mexico. The study is an extension of that started with Pecos pottery for Dr. Kidder at the inception of the Ceramic Technology project. Finally, Mr. Spangler was directed in the study of a collection of miscellaneous materials from Uaxactun, including mortars and plaster, and materials from vessel interiors. A different approach was made in the study of plasters from that usually followed. Chemical analysis, because of the nature of the processes taking place in the calcination, slaking, and subsequent exposure of limestone plasters, does not show whether or not they were calcined; therefore, for the Uaxactun samples, chemical and mechanical separations were made and the residues and fractions studied microscopically. In this way indirect evidence of calcination of some of the plaster, and of the use of some unburned limestone, was obtained. The microscopic features of the residues were so distinctive that they gave promise of the possibility of identifying limestones from different quarries.

The principal petrographic work undertaken during the year was the study of pottery from the Guatemalan highlands, including a comparison of paste types of a western highland site, Tajumulco (material lent through the courtesy of the Museum of New Mexico), and southern highland pottery. A special study of plumbate pottery from the highlands, Salvador, and Chichen Itzá was made. Petrographic evidence gives promise of throwing light on the place of origin of this important ware.

HISTORY OF YUCATÁN

F. V. Scholes, R. S. Chamberlain, and R. L. Roys

In September 1939 the headquarters of the History of Yucatán project were transferred from Cambridge to Washington, D. C., where offices were provided for Mr. Scholes, Dr. Chamberlain, and Miss Adams in the Administration Building of Carnegie Institution. Mr. Roys has continued to reside in

Vancouver but he plans to move to Seattle about September 1, 1940.

As stated in earlier annual reports, the lack of published documentary sources, as well as detailed monographic studies, on the colonial history of Yucatán has made it necessary to devote a long period of time to preliminary

archival investigations. The study of Latin American history as a whole is characterized by these same limiting factors, although the printed materials, both documents and monographs, are more extensive for other areas than for Yucatán. It is this state of affairs that makes many phases of Latin American history virgin fields for research, and at the same time imposes definite conditions on the character of investigations. In other branches of history, such as that of the United States, England, or modern Europe, students have the advantage of a large accumulation of detailed monographs and special articles summarizing spade-work research and serving as basis for works of synthesis. The Latin American field has lagged behind the others in this respect, with the result that there are few major topics on which sound generalization is possible except after prolonged research in the original documentary sources. This is particularly true of the colonial history of Yucatán, for which the available published sources that have merit consist of a few volumes of early chronicles and documents.

Publications by members of the History of Yucatán project up to the present time have consisted in reproduction of documents and short papers on special topics. The immediate future calls for the publication of four or five monographs on special problems or limited chronological periods. These publications, completed and in preparation, will lay the foundations for the writing of the general history of Yucatán which is the chief aim of the project.

During the past year progress has been made in the preparation of the monographic publications. Mr. Scholes has pushed forward his investigations on the life and times of Bishop Landa. Miss Adams has extracted a mass of documentary material, consisting of royal decrees, lawsuits, petitions, and administrative orders on the *encomienda* system, forced labor, village government, and other phases of Indian administration in Yucatán. Materials of special interest for the research of Dr. Morley and Mr. Roys have been made available to them. Miss Adams and Mr. Scholes collaborated with Mr. Roys in the

preparation of the paper on the early history of Cozumel, published during the year as "Contributions to American Anthropology and History," No. 30. The monograph on the *cacicazgo* of Acalan-Tixchel, on which Mr. Scholes, Mr. Roys, and Dr. Chamberlain are collaborating, will be completed within a few months.

Dr. Chamberlain has been engaged in the preparation of the final draft of his study on the conquest of Yucatán. It was his original intention to approach this subject as a principal phase of the career of the Adelantado Francisco de Montejo, who also played an important role in the early history of Honduras and for a time was governor of Chiapas. The method thus envisaged was biographical and required that the history of Yucatán and Honduras should be woven about the figure of Montejo. As the preparation of his manuscript advanced he became convinced that such a method was not only illogical but lacking in unity. In view of the detailed treatment required, a narrative of events in Yucatán and Honduras drawn up on a biographical basis tended on the one hand to submerge Montejo as an individual and on the other to distort the history of the two provinces. This would be unfortunate, since no exhaustive biographical study of Montejo, one of the outstanding lesser conquistadores of Spanish America, has yet appeared and little has been written concerning the history of Honduras during his years in authority there. In view of these considerations, Dr. Chamberlain has decided to divide his study into two separate monographs, one on the conquest of Yucatán and the closely associated province of Tabasco, and the other on the history of Honduras through the establishment of the Audiencia de los Confines. Each will be a unit in itself. At a later date he proposes to publish a less detailed study of Montejo as one of the founders of the Spanish empire in the New World. Preparation of the manuscript on the conquest of Yucatán is now in its final stages. Dr. Chamberlain also published during the past year a short paper on the lineage of Montejo.

Much of the past year has been occupied

by Mr. Roys in seeing through the press *The titles of Ebtun; Report and census of the Indians of Cozumel, 1570;* and *Personal names of the Maya of Yucatan* (see bibliography).

The annotation of the Xiu family papers has been reviewed and completed; and for the introduction to these documents Mr. Roys has made a study of Indian nobility during the colonial period (see Year Books Nos. 31, 33, and 38).

When the Spaniards arrived in Yucatán, they found a hereditary ruling class of long standing; but instead of attempting to destroy it, they appear to have seen in this Indian aristocracy a parallel to certain features of their own feudal system, which they preserved and encouraged. The Xiu *probanzas*, or proofs of nobility, constitute the chief evidence of the manner in which this institution was maintained in Yucatán, but occasional references to it occur elsewhere. Mr. Scholes has also furnished copies of many documents from the National Archive of Mexico, which have aided greatly in understanding the situation in Yucatán.

In both Yucatán and Mexico the Spaniards called the higher nobility caciques and sometimes natural lords; lesser nobles were designated as hidalgos in Yucatán and *principales* in Mexico. As early as 1512 special treatment was prescribed by Spanish law for Indian chiefs in the West Indies; and later Philip II and his successors issued cedulas maintaining the rank privileges of caciques generally.

In colonial Yucatán the hereditary caciques were usually descendants of the pre-Spanish *batab*, or local head of a town; but some, like the Xiu, who were also called natural lords, were descended from the *halach uinic*, or territorial ruler. The cacique had the title of Don and was exempt from tribute and forced labor. His town was obliged to support him, rebuild and repair his home when necessary, and furnish him with domestic service. His precise functions are somewhat uncertain, as there was also an Indian governor in the town. We are told that the hereditary cacique had charge of and governed his town and was obeyed by the governor, but the functions

prescribed in the latter's commission are so numerous that it is difficult to determine what was left to the cacique. The Laws of the Indies confuse the two offices.

The cacique, however, had a place in the town corporation, where he doubtless exercised much influence. In Yucatán the Xiu caciques captured and returned fugitive Indians to their communities; they were also sometimes sent to other towns and appointed governor in place of an incumbent who was neglectful of his duties. In Mexico Don Francisco Montezuma was empowered by the Viceroy to protect his people from abuse by Spanish and Mexican shepherds. We find other caciques taking over the governor's duties during disputed elections, and successfully appealing in behalf of their towns for relief from illegal taxation, too frequent official visits of inspection, and interference by the clergy in local elections. From such activities as we find recorded, the cacique appears to have been more concerned with emergencies than with the usual procedure of municipal government.

Hereditary caciques apparently enjoyed more prestige and power in Mexico than in Yucatán, possibly owing to their superior economic position. We have little evidence of wealthy caciques in Yucatán, but in Mexico we find them owning extensive tracts of land, large herds of cattle, and various industries.

In Mexico the distinction between the caciques and lesser nobility continued to be observed down to the end of the colonial period; but in Yucatán after the middle of the eighteenth century they were all called hidalgos. They retained their exemption from tribute and forced labor, but the title of cacique had been appropriated by the town governor, although his office was only temporary. With the end of the Spanish regime in 1821, Indian nobility lost its legal standing, but some of the baptismal records of Yucatán continued to designate certain infants as hidalgos down to the middle of the nineteenth century.

By preserving and conciliating the Indian nobility the Spanish administration appears

to have forwarded its own interests as well as those of the class so favored. The conquerors were few in number compared with the native population, and such a policy, in spite of some defection on the part of individuals, tended to keep the natural leaders of the Indians loyal, or at least acquiescent, to the Spanish regime. In Yucatán, the subject of this study, we believe that it aided greatly in controlling the natives and lessened the chances of insurrection. In any case the institution of native nobility in Yucatán and New Spain assumed an importance in the life of the Indian communities which has been very little realized by historians.

During the year Mr. Scholes has also given part of his time to the completion of studies on the history of New Mexico in the seventeenth century, on which he was engaged before becoming a member of the Division staff. A paper on the Jumano Indians, prepared in collaboration with Dr. H. P. Mera, of the Laboratory of Anthropology in Santa Fe, was published in "Contributions to American Anthropology and History," No. 34.

In accordance with an agreement made with the officials of the Mexican National Archive, Sr. Rubio Mañé spent the past year working on a guide to the Papeles de Bienes Nacionales in that archive.

SOCIOLOGY AND LINGUISTICS

R. Redfield, S. Tax, and A. Villa

During the year the ethnologic and linguistic research of the Division was advanced chiefly by the study of materials already collected, and by their preparation for publication. No field work, directly within the research program of this group of workers, was carried on during the period. Dr. Redfield devoted much time to the manuscript summarizing the comparative study made of four communities in Yucatán. This manuscript has now been completed. Dr. Redfield also wrote and published a general paper, "The Indian in Mexico," for the *Annals of the Academy of Political and Social Science* (March 1940) and, with Mrs. Redfield, wrote *Disease and its treatment in Dzitas, Yucatan* (see bibliography). Dr. Tax's presence in Chicago during the year allowed Drs. Tax and Redfield to collaborate in the review and annotation of a number of manuscripts in the field of Maya ethnology or that of Guatemala or Mexico generally: manuscripts by Professor C. L. Jones, Dr. Ruth Bunzel, and Messrs. R. Stadelman, O. LaFarge, C. Wagley, and F. W. McBryde. Dr. Tax did the greater part of this work, and in connection with the manuscript of Dr. Bunzel, on Chichicastenango, prepared, for purposes of comparison, a reorganization of data collected there by himself in 1934-1935 and 1938-

1939; this work will continue. A major enterprise brought to completion by Dr. Tax was the editing and preparation for the press of a manuscript by Mr. Charles Wisdom on the Chorti of Guatemala.

Dr. Tax devoted most of his time, however, to preparation of his own materials. Attention was given chiefly to two monographs on the town of Panajachel, the first on economics and the second on the general culture of the community. The economics paper, initiated at the beginning of the year, was about half completed; two-thirds of the other were completed except for final revision and typing. In all, some four hundred pages of typescript were prepared for the press; it is expected that by October this number will be increased to nearly a thousand. In connection with conflicting data on land utilization in Panajachel, a short conference with Mr. F. W. McBryde was held in Columbus, Ohio, in March; notes were compared and difficulties successfully resolved. The only other departure from Chicago was a trip to Indianapolis in April, when Dr. Tax read a paper on "Acculturation in Guatemala" before the American Anthropological Association.

During the year supervision of the researches of Sr. Juan Rosales on the town of San Pedro was continued by correspondence.

Sr. Rosales made Solola his headquarters. The introductory sections of a joint monograph in Spanish were completed, but progress on this manuscript was continually interrupted by acquisition of new data on both San Pedro and Panajachel. Sr. Rosales made several trips to Panajachel, and also received informants from there, to confirm and elaborate items of information received in connection with the preparation of the two Panajachel monographs. He also made extended visits to San Pedro, and spent considerable time with San Pedro informants in Solola. Two opportunities in this connection were especially fortunate. First, the complete confidence of a San Pedro shaman was won, and for the first time in our experience in Guatemala full and reliable information on the esoteric aspects of his profession was obtained. Second, a literate Indian working in the town hall of San Pedro was employed to keep full daily records of court proceedings; the resulting material is an invaluable supplement of cases dealing with most phases of local Indian life. In all, no less than 700,000 words of typewritten notes on San Pedro culture have now been collected.

Sr. Alfonso Villa was occupied chiefly with the preparation of his monograph on the Maya of the X-Cacal region of east central Quintana Roo. The composition of a long historical section required Sr. Villa to devote much time to the consideration of documentary sources. The Quintana Roo manuscript is nearing completion. For about two months

Sr. Villa interrupted this work in order to participate, as field assistant investigating the general social structure of certain villages, in the Tarascan project operated by the Mexican Government, under the direction of Dr. Morris Swadesh and Dr. Rubín de la Borrilla, in connection with its recently adopted policy of developing methods of writing and teaching in native Indian languages. In this connection Sr. Villa spent some weeks in Michoacan. He attended the First International Indianist Congress at Patzcuaro, and presented a paper on "The social organization of the Tzeltal of Chiapas."

In the spring of 1940, a Social Science Research Council fellowship was awarded to Mr. Benjamin Paul, student in anthropology at the University of Chicago, for ethnological work in Guatemala. His enterprise will be supervised by Drs. Redfield and Tax and coordinated with the field program of the Institution.

It proved impossible to assemble for a proposed conference most of the workers of the country who are active in Maya ethnology. Members of the interested group have, however, agreed to prepare topical memoranda to be used as a basis for discussion when, probably next year, the conference is held.

Dr. Andrade also remained in the United States during the year. Work on the linguistic project consisted mainly in the analysis and organization of data gathered in previous field trips. The grammar of Yucatec is almost finished.

UNITED STATES HISTORY

Volume V of Dr. Stock's *Proceedings and debates of the British Parliaments respecting North America* is nearing completion; it is expected that the volume will be ready for the press next spring. Volume IV appeared in 1937. The editor's visit to England the following year for examination of materials for subsequent volumes (a fortunate choice of years for such a search) delayed the preparation of the text for this present volume. The period covered by volume IV closed with the outbreak of the war with Spain, 1739,

which continued in expanding scope until the treaty of Aix-la-Chapelle, 1748. The materials to be printed in the next volume show how these wars touched America through parliamentary action. The legislation enacted was intended to aid in the prosecution of the war by modification of the trade acts, by numerous supply bills affecting duties and bounties, and by other measures of a miscellaneous nature. The affairs of Georgia were again frequently before the House of Commons; colonial bills of credit received serious consideration; the

trade of the sugar islands, the manufactures of the northern colonies, and various petitions and accounts were given attention. The amount of space necessary for reports of debates is considerably less than that devoted to lengthy and repetitious speeches in volume IV. The volume will probably cover the remaining years of the reign of George II, bringing the account to 1760.

The *Guide to materials for American history in the libraries and archives of Paris* is still in the process of completion. The manuscript for volume II, dealing with the Foreign

Office Archives, was completed during the summer by Dr. John J. Meng, working under the direction of Dr. Waldo G. Leland. This volume will include materials to a comparatively recent date for European archives, 1860. All important remaining gaps in the materials were filled before the outbreak of the present hostilities, so that the *Guide* promises to be an important aid to historians, whatever the fate of the archives themselves. Work has already been started on volume III, which will include a descriptive guide to the archives of the War Office.

HISTORY OF SCIENCE

George Sarton

Introduction to the history of science. Dr. Sarton's analytic work relative to volume III, "Science and learning in the fourteenth century," is now virtually completed. The only notes which still need revision are a few in the Hindu (Sanskrit) group, and a few odd Oriental notes. The Chinese notes are completed as far as Dr. Sarton is concerned, but are now being revised by a Chinese scholar, Mr. Hsiang-Lin Shih, who will make sure that the Chinese characters are exactly represented and who may be able to add biographical information derived from Chinese sources unavailable to Dr. Sarton. A complete index to the Chinese and Japanese notes of volumes I to III is being prepared, as it is realized that the lack of Chinese characters in volumes I and II was a great drawback, a constant cause of delay and confusion. The Chinese characters relative to the Japanese notes are being determined by Dr. Shio Sakanishi, of the Oriental Division of the Library of Congress; those relative to the Chinese notes are being written by Dr. Sarton. The whole index may eventually be printed, thanks to the friendly cooperation of the Harvard-Yenching Institute.

As the work is now nearing completion, it may be recalled that the foundations of it were laid by Dr. Sarton in Wondelgem, Belgium, in 1913-1914, that effort being interrupted by the first German invasion of

Belgium. As he was then planning the whole *Introduction* (down to our own times), he collected notes relative to every period, including, naturally, the fourteenth century. When he was able to resume work under the auspices of the Carnegie Institution, as the investigations proceeded it became clear that his original program would have to be revised. The bulk of his notes relative not only to the fourteenth century but even to the fifteenth were ready when he prepared volume II for publication. However, by the time he had reached the end of the thirteenth century the mass of manuscript ready for printing was already so large that it was decided to restrict volume II to the twelfth and thirteenth centuries, instead of centuries twelve to fifteen, as first planned. As a result the notes on the fourteenth and fifteenth centuries were temporarily shelved, but his new edition of them is incomparably richer than was possible ten years ago. To put it briefly, volume I of the *Introduction* (1927) was based on the accumulated knowledge and collections of a dozen years, volume II (1931) on those of sixteen years, volume III on those of twenty-six years. The latter volume will still, in Dr. Sarton's opinion, be very imperfect, but will represent an effort of sufficient length and strength to deserve systematic correction.

Other investigations. Most of Dr. Sarton's attention having been devoted to the *Intro-*

duction, he had only time for the review of a few books and other similar interludes; he continued, however, his Arabic and Chinese studies.

Dr. Pogo pursued his investigations of the lunar calendar of the Maya.

Mr. I. Bernard Cohen continued his studies of the history of electricity and theoretical optics of the seventeenth and eighteenth centuries. Part of this work consisted in the preparation of a new edition of Benjamin Franklin's *Experiments and observations on electricity and magnetism*, which has been out of print for more than two hundred and fifty years. This is to be prefaced by a lengthy study on Franklin's scientific work and its essential significance.

Editing of Isis and Osiris. The proofreading was entirely handled by Dr. Pogo, who conducted all correspondence with contributors and much administrative correspondence relative to both journals.

The history of *Isis* repeats itself. It was founded in 1912-1913, but hardly had five numbers appeared (volume 1 and half of volume 2) when it was interrupted by the German invasion of Belgium. Publication was resumed in 1919, the editing being done in this country but the printing in Belgium. In 1924, the History of Science Society was founded in Boston to guarantee and promote the publication of *Isis*. Thus far eighty-three numbers have appeared, forming more than thirty large volumes. The second invasion of Belgium, in May of this year, stopped *Isis* for a second time. At the moment of its occurrence four more numbers of *Isis* (84 to 87) plus two volumes of *Osiris* (8 and 9) were in various stages of printing. From 1941 on, *Isis* will be printed in the United States.

On account of the suppression of *Isis* it is

possible to report fewer publications, but much work was done for the volumes which remain unpublished. During the course of last year only two numbers of *Isis* (82 and 83) were actually issued to members, plus two volumes of *Osiris* (6 and 7): a total of 1994 pages illustrated with 8 plates and 117 figures, containing 25 memoirs, 18 shorter notes, 45 reviews, and 1160 bibliographic notes.

One of the memoirs is so important for the development of American scholarship in the field of the history of science that it deserves separate mention. This is the "Catalogue of Latin and vernacular alchemical manuscripts in the United States and Canada," by Dr. William Jerome Wilson (844 pp., *Osiris*, vol. 4, 1939), the most elaborate work of its kind ever published.

Lectures. Dr. Sarton gave a course of about thirty-three lectures on the history of mathematics at Harvard University and also at Radcliffe College. He directed a seminar on the history of science and learning in Harvard University (twenty-five meetings, twelve of which were conducted by himself).

He addressed the Fifth International Congress for the Unity of Science in Emerson Hall, Cambridge, on September 4, presided over some of the meetings, and invited the members to an exhibition of the apparatus available to scholars in Widener 185-189. On January 29 he gave a lecture at the Fogg Museum on the history of science versus the history of art; on February 6 he addressed the mathematical faculty of Harvard University at their annual dinner; on April 8 he received a delegation from Brown University led by Professor J. Walter Wilson, and explained to them the work done by him for the Carnegie Institution.

PUBLICATIONS

Margaret W. Harrison

In September 1939 the Division published *The titles of Ebtun*, by Ralph L. Roys. This book is a study of the archives of Ebtun, an Indian town in eastern Yucatán, from 1600 to 1833. A historical survey introduces the

documents—agreements with other towns, transfers of property, records of lawsuits and wills—which are transcribed in Maya and in Spanish, translated, and annotated.

At the end of the year *Archaeological*

studies in the La Plata district: southwestern Colorado and northwestern New Mexico, by Earl H. Morris, was published. To this comprehensive history of the material arts of the Basket Maker-Pueblo Indians as practiced in this region between A.D. 700 and 1300 is appended a discussion of the technology of La Plata pottery, by Anna O. Shepard. This was the first Division publication to use the two-column format, which proved most satisfactory both in style and in economy.

The second and final volume of taxonomic papers in botany was published in June 1940. This group, *Botany of the Maya area: miscellaneous papers XIV-XXI*, as well as the thirteen monographs printed in 1936, was edited by Cyrus Longworth Lundell, Curator of the University of Michigan Herbarium and Research Associate of the Carnegie Institution of Washington. The publication is the report of the 1936 expedition to British Honduras engaged in jointly by these two organizations.

Also in June appeared the sixth volume of "Contributions to American Anthropology and History." In the first paper of this series, *Report and census of the Indians of Cozumel, 1570* (Contribution 30), Ralph L. Roys, with the collaboration of France V. Scholes and Eleanor B. Adams, writes a brief history of Cozumel as one of the three great religious sanctuaries of the New Empire Maya, and transcribes and translates six documents, including a census of the Indians and a report on the island by Cristobal Asensio. In *Personal names of the Maya of Yucatan* (Contribution 31), Mr. Roys discusses the importance of personal names to the history and ethnog-

raphy of the Yucatecan Maya, listing patronymics, *naal* or maternal names, and boy names, together with their definitions. *Disease and its treatment in Dzitas, Yucatan* (Contribution 32) is a study of village culture derived by Robert and Margaret Park Redfield principally from interviews on medical lore with a curer, a midwife, and an amateur, and also from interviews with two men, one a believer in the old agricultural-magical beliefs and rituals, the other a relative sophisticate. The Division compiled *Maize cultivation in northwestern Guatemala* (Contribution 33) from data collected in the field by Raymond Stadelman in order to gain information on the probable early methods of cultivation and on the role of maize in the economy of pre-Columbian inhabitants of the Maya area. This paper is amplified with about 100 tables on the statistics and linguistics of this cultivation and with an important list of terms. A joint historical and archaeological approach, by France V. Scholes and H. P. Mera, respectively, to the problem of defining the cultural affiliations of the Jumano tribes and settlements of the southwestern United States records new evidence in *Some aspects of the Jumano problem* (Contribution 34).

Now going through the press and to be reproduced by the multolith process is *Late ceramic horizons at Benque Viejo, British Honduras*, by J. Eric S. Thompson, with notes on the classification of the painted wares by Anna O. Shepard. This paper will form Contribution 35 in the seventh volume of the "Contributions" series.

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SPECIAL PROJECTS: HISTORICAL RESEARCH

MARION E. BLAKE, Bradford, Vermont. *Preparation and completion for publication of the first part of a monograph on Roman building construction, based upon materials accumulated by the late Dr. Esther B. Van Deman.* (For previous report see Year Book No. 38.)

This report covers the period from July 1, 1939 to May 15, 1940, when Dr. Blake found it necessary to make preparations for an unexpected return from Italy to the United States. Unfortunately this was at a time when writing was proceeding rapidly. In spite of enforced difficulties and delays she has completed a first draft of her chapter on materials and has well in hand the chapters on mortar, concrete, and wall facings. She has filed with the Institution a completed section of manuscript on the latter subject.

While in the United States Dr. Blake expects to proceed with her work as rapidly as possible, with the intention of giving full time to the project until the completion of all that can be done in America pending a return to Italy at the earliest possible moment.

During the year Dr. Blake was able to give final preparation to her manuscript on "The mosaics of the late Empire in Rome and vicinity," to appear in volume 17 of the *Memoirs of the American Academy in Rome*.

As a result of her experience, Dr. Blake is more than ever convinced of the desirability of publication of the results of Dr. Van Deman's studies. Italian scholars will welcome such a comprehensive and up-to-date work on Roman construction, and American scholars have been awaiting publication for over a quarter of a century.

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FRANS BLOM, Tulane University, New Orleans, Louisiana. *Preparation of a new edition of the Map of the Maya Area.*

Under a grant from the Carnegie Corporation of New York to the Carnegie Institution of Washington, the Middle American Research Institute of Tulane University in May 1939 started preparation for publication of a new edition of the Map of the Maya Area, compiled originally in 1924 by Oliver G. Ricketson, Jr., and Frans Blom. The map is to be issued in six sections, each measuring approximately 80 by 130 cm. Gerhardt Kramer, Associate in Architecture in the Middle American Research Institute, is chief of the map project. His Spanish-English assistant has been S. K. Lowe.

Considerable research has been involved in preparing this new edition, and, with it, bringing up to date the thousands of cards on which are recorded data about archaeological sites. Determining such things as

exact locations of sites and modern settlements, spelling of place names loosely reported, recent discoveries in the Maya Area, names of individuals to be credited with finding new sites, and the like have made the progress of the map necessarily slow.

In order to insure against inaccuracies and omissions, about forty individuals familiar with certain regions in the area included in the map were asked to serve on an Honorary Advisory Committee on this project. A preliminary draft of the map was completed first and sent to all members of this committee for correction and approval. Based on these corrections and additions, the final draft of the map now is being prepared, and should be completed for distribution by the end of 1940.

VERNE E. CHATELAIN, St. Augustine, Florida. *The St. Augustine Historical Program.* (For previous reports see Year Books Nos. 36-38.)

Financial aid in support of certain studies in connection with the St. Augustine Historical Program has been supplied in part by the Carnegie Institution of Washington.

This program is entering its fifth year. Preliminary investigations, first undertaken in 1936, have now made it possible to determine objectives and future procedure. The study of various phases of the colonial period as they relate to St. Augustine is sufficiently complete to ascertain with a reasonable degree of accuracy essential historical data, including sites of important events, and to permit intelligent planning for their protection and use.

The settlement of St. Augustine in the year 1565 is a historical event of transcendent importance that cannot properly be considered merely as a prelude to the story of English colonization on the Atlantic seaboard. Its true significance in history can be appreciated only in the light of Spain's imperial policy in the New World, marking, as it did, the successful culmination of that nation's efforts to establish a military outpost in Florida, which would serve to control the frontier lying north of its already flourishing colonies in the West Indies and adjacent to the Caribbean Sea and Gulf of Mexico, and more particularly to help protect the sea lanes used in shipping the valuable cargoes of the Western Hemisphere to Spanish ports in the Old World.

For these reasons, St. Augustine, aside from the fact that it enjoys the distinction of being the oldest permanent community settled by Europeans in the United States, affords an unusual opportunity for understanding the Spanish colonization of all the Americas; and especially so, because abundant written records and physical remains of its long history exist and can easily be used for this purpose. Of some significance, also, is the fact that by means of such a program of development as that planned here, the common bonds of traditional history and culture extending

through all the American republics may be examined and appreciated. Needless to add, there is an important value to be gained from such an enterprise at this time, in the shape of better relations and a stronger solidarity in the Western Hemisphere.

The plans for the future include the protection and marking of important sites connected with the history of St. Augustine, as well as the general treatment of the environment to render it harmonious and effective. In addition, it is proposed to concentrate at St. Augustine copies, if not the originals, of many of the documentary records of its history, housing these appropriately and creating also a historical museum, in which the story through its many stages of transition will be visually and clearly presented. Moreover, it is planned to develop a cultural center wherein exhibits and records relating to the other American republics may be accessible to visitors. A Joint Resolution has recently been introduced in Congress, providing for participation by the United States government in the cultural center.

During the past year a permanent advisory committee for the Program has been organized, consisting of representatives of the American Council of Learned Societies, the American Philosophical Society, the National Park Service, and the Carnegie Institution of Washington. Dr. Waldo G. Leland, Director of the American Council of Learned Societies, is Chairman of this committee. The St. Augustine Historical Preservation and Restoration Association has been strengthened by the appointment of four new members to the Board of Directors, namely, Dr. Herbert E. Bolton, of the University of California, Dean William E. Lingelbach, of the University of Pennsylvania, Mr. Owen D. Young, and Dr. Leland. A financial committee within the Association has now been organized, and active steps are being taken to meet the problem of raising funds. A brochure outlining

the features of the formulated plans is being prepared. Verne E. Chatelain continues as Director of the general program.

The work entitled *The defenses of Spanish*

Florida, 1565 to 1763, which is one of the series of studies undertaken in connection with the St. Augustine Historical Program, is now in press.

E. A. LOWE, The Institute for Advanced Study, Princeton, New Jersey. *Collection and study of paleographical material.* (For previous reports see Year Books Nos. 9-35, 37, 38.)

Field work was continued in Italy during the summer of 1939. Revision of material dealt with in volume IV of *Codices latini antiquiores* (see previous report) was brought to completion. All the manuscripts were re-examined *in situ*, with the exception of a single item in Zara. Knowledge of this newly discovered fragment came too late for a journey to Dalmatia, but its inclusion in volume IV was imperative since Zara is now Italian territory. Dr. Lowe spent the months of September and October 1939 in Oxford seeing the collotypes through the press and preparing the descriptions of the plates. He put the copy in the printer's hands before sailing

for America, and first proofs were received in Princeton during the early part of this year. It may seem advisable to finish volume IV with the material now available and get it out while the Clarendon Press is still prepared to cope with such publications.

In the course of work on volume IV, two problems became of increasing interest. One is the tracing of the development of *capitalis rustica*, the script in which our oldest manuscripts of the classics are written; the other concerns the history of the Bobbio palimpsests and the fate of the Library of Cassiodorus in Vivarium. Work on these two problems will be pursued during the coming year.

PALEONTOLOGY, EARLY MAN, AND HISTORICAL GEOLOGY

REPORT ON PRESIDENT-EMERITUS RESEARCH WORK OF JOHN C. MERRIAM AND ASSOCIATES. (For previous reports see Year Books Nos. 20-38.)

The objectives of study were defined in the report for the year 1939, and the statement covering the present year therefore concerns itself in a large measure with a record of advance in contributions. A considerable number of the projects have been formulated in terms of work conducted by associates who are responsible personally for the detail of their reports. In some instances these investigations have been carried farther than, in all probability, they would have gone without the opportunity for cooperative research presented by these projects.

All the programs planned and initiated in 1939 have advanced vigorously toward the goals as originally defined, but, in most cases, the problems have led to situations in which new avenues of research have opened and for which investigation has seemed important in obtaining a solution for the projects as originally set up. The results of work of the past year have therefore given broader and, in some respects, clearer pictures than were at first suggested.

In preparing this report, it has seemed wise to group the data in considerable part according to the methods of presentation used by individual investigators. The results are therefore presented in large part under the names of cooperating investigators. It is important to note that the objective of this research effort has been planned to include the carrying forward of projects now under way by individual investigators or by representatives of various institutions in such manner as to guarantee the advance of knowledge in the fields concerned by such methods as may seem desirable at different times and in different places and for so long a time as may be required for obtaining a clear view of the essential facts and their relations to each other.

In accordance with the plan outlined above, the reports of John P. Buwalda, Chester

Stock, E. L. Packard, E. L. Furlong, Edwin D. McKee, Remington Kellogg, and R. W. Chaney appear under separate heads and in the form presented by these investigators.

A large group of studies centered in considerable part upon researches in the history of early man in south central Oregon are represented in this report largely by separate statements, including those of L. S. Cressman, Ira S. Allison, and Ernst Antevs. It is important to note that advance in study of the problem of early man in Oregon, as also of many related problems, including the geological history of the eastern Oregon region, has gone forward in a most satisfactory way to illuminate the story of early man and of his environment in eastern Oregon. It is clear that out of the investigations under way there will come not only an exceptionally important study on problems of early human history but also a number of independent monographs ranging through the whole field of geology, paleontology, archaeology, ethnology, and the geological history of climates within the periods immediately preceding the present.

It is also to be noted that the methods of study and the modes of cooperation set up in these investigations have established a working relation between groups of investigators in different subjects and in different institutions which will quite certainly affect in a favorable way the whole scientific and educational program of the institutions and agencies involved.

The study of problems relating to basic questions in science and their meaning in terms of human interest and value, as outlined in the report of 1939, has been continued with special emphasis upon those aspects which may be expected to contribute in some measure toward the understanding of fundamental philosophical problems of the present day. This phase of the work has been

carried forward with the feeling that in the present disturbed condition of the world every effort should be made to bring into close relation those aspects of human conduct, of philosophy, of religion, and of science that may be valuable in our attempts to build a philosophy upon which the new world order may rest with reasonable expectation of stability. This subject is being considered in several studies by the writer which will appear in the near future.

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PALEONTOLOGICAL RESEARCHES

Chester Stock

During 1940 the volume of Contributions to Paleontology constituting Publication No. 514 was completed and published. This comprises a series of nine papers, eight of which relate to special studies that have been conducted in the Tertiary of California, Oregon, and Nevada. The first three papers were listed in last year's report. For those published in 1940, see the bibliography below.

There has been brought to completion a comprehensive report entitled "A Tertiary mammalian fauna from the San Antonio Mountains near Tonopah, Nevada," by Paul C. Henshaw. This relates to a mammalian assemblage found in Miocene deposits northeast of Tonopah, Nevada, and furnishes for the first time valuable evidence as to the age of the so-called Esmeralda beds in this region. The paper awaits completion of illustrative materials and will be submitted for publication by the Institution as a Contribution to Paleontology. A second paper, entitled "Later Tertiary Equidae from the Tejon Hills, California," by Arthur B. Drescher, has been

submitted to the Institution for publication. This describes important fossil horse material from a significant Tertiary horizon in the southern San Joaquin Valley.

Several visits were made for consultation with Professor George F. Beck, at Washington State Teachers College, on problems relating to the Ellensburg formation and fauna. These visits have given opportunity to examine the Ellensburg at the type locality for additional fossil remains and to study other vertebrate occurrences in the vicinity of Yakima, and in Washington east of the Columbia River. Vertebrate fossils from several of these horizons are now being studied in preparation for a report on the Ellensburg fauna.

During the past summer a field party of eight men from the California Institute of Technology spent two and a half months in field work in eastern Oregon and southern Washington, which resulted in several noteworthy contributions to our knowledge of the paleontological history of these regions, as follows:

1. Important mammalian remains representing particularly the horse *Merychippus* were excavated in Miocene deposits near Madras, Oregon. Determination of the age of these deposits is of significance, since the fossil materials furnish an adequate basis for comparison with similar remains from the Mascall formation at the type locality in the John Day Basin.

2. Examination of a geologic section at Beatty Butte, southwest of Blitzen, in southern Oregon has brought to light a Miocene mammalian assemblage in a region from which no Tertiary vertebrate records have been obtained heretofore. Determination of age and relationships of this fauna will shed light on the sequence of events in the later Tertiary history of the area lying between Harney Lake to the north and the Steens Mountains to the south.

3. Systematic collecting was carried forward in the John Day deposits exposed in the John Day Basin near Spray. This work

furnished added materials of value in a comprehensive review of the John Day fauna now under way.

4. Certain later Tertiary deposits resting on basaltic lavas south of the Columbia River and east of Arlington were extensively explored for fossil materials. Satisfactory collections of mammalian remains were obtained, and a further study of these specimens will shed much light upon the age relations of the strata. In connection with this problem, the basaltic lavas and an intercalated stratum of tuff were examined in detail at Roosevelt, Washington, on the north side of the Columbia River. Fossil materials obtained here clearly indicate that the intercalated tuffs contain Miocene mammals and are not to be regarded as of the same age as the sands from which the fauna was obtained east of Arlington. Collection of this material therefore clarifies certain aspects of the geological problem involved in a study of the lavas and associated sediments exposed along the Columbia River in the vicinity of Arlington and Roosevelt.

Quaternary studies have emphasized particularly a consideration of Rancho La Brea and its development as a public park having unique scientific features. At the request of Hon. Roger Jessup, presiding Chairman of the Board of Supervisors of Los Angeles County, Dr. John C. Merriam addressed the Board on Rancho La Brea and its significance as a historical record. The members of the Board of Governors and the Director of the Los Angeles Museum were also present. This meeting occurred on February 20, 1940, and as a result the Board of Supervisors instructed the Regional Planning Commission to formulate a recommendation for the improvement of Rancho La Brea, or Hancock Park as it is now known, as a W. P. A. project for 1940-1941. The approved plan includes the erection of an observation station wherein will be exhibited a characteristic fossiliferous asphalt deposit and certain accessory materials, restoration of the Hancock ranch house, the erection of supplementary buildings, and planting. Dr. Ralph W. Chaney

has assisted in the preparation of a list of plants to be used in the re-establishment of the characteristic flora which grew in this region of southern California during Pleistocene time. Many of these plants are definitely recorded in the asphalt deposits. Preliminary steps have also been taken to determine the best talent available for sculpturing life-size restorations of the characteristic animals found in the brea beds.

A review of the prehistory of man, entitled "Prehistoric archeology," has been completed by Chester Stock, and submitted for publication in the semicentennial anniversary volume of the Geological Society of America.

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A STUDY OF PLIOCENE ANTELOPES

Eustace L. Furlong

A paper has been prepared on the history of the antelope group, and presented for publication. The contribution covers both description of new material and the relationships of some of the principal forms known

in America. There is presented a review of the original descriptions and specimens of *Ilingoceros* and *Sphenophalos* from the Thousand Creek beds of Nevada, and of later works by various authors. Additional material of these genera in the California Institute of Technology collections has been described, with comments on their occurrence and possible relationships.

Included in the study is a description of a new type of Pliocene antilocaprid, with a discussion of its morphology and place in the evolutionary series of Antilocapridae as known at present. The new genus is represented by numerous skeletal parts in the California Institute of Technology collections from Pliocene deposits in the Rincon region of Mexico. The new genus and species is represented by illustrations of appropriate specimens, and a chart showing types of horn cores of antilocaprids from the Miocene period to the living *Antilocapra americana*.

RESEARCHES ON HISTORY OF TERTIARY FAUNAS
IN RELATION TO CRUSTAL MOVEMENTS IN
MOUNTAIN RANGES OF SOUTHERN
CALIFORNIA

John P. Buwalda

Tehachapi Mountains. Three early to middle Tertiary formations, the Witnet, Kinnick, and Bopesta in ascending order, extend over considerable areas in the Tehachapi Mountains beneath and north and east of Tehachapi Valley. Each formation is unconformable on the one next older, and the time interval from the oldest to the youngest probably represents a considerable fraction of the Tertiary period. Continued mapping of this region and of the adjacent part of the Mohave Desert indicates that these three formations all extend to or very near the Garlock fault, which separates the mountains from the desert, but none of them has been found on the desert side of the fault. The Kinnick and the Bopesta formations, containing the Lower Miocene Phillips Ranch and the Upper Miocene Cache Peak mammalian horizons respectively, form the upper part of the scarp created by the Garlock fault

north of Mohave, and either were cut off by the fault or, conceivably, were limited in area of deposition by a scarp on the desert side of the Garlock fault facing north, or in the opposite direction from the present one. The probably pre-Miocene Witnet beds do not reach the scarp, but approach it with a thickness of many hundreds of feet, and presumably had the same historical relation to the fault as the two younger formations.

The adjacent part of the Mohave Desert, across the fault, is largely covered by alluvial fans, but Tertiary formations are exposed in limited areas. South of Warren, and within a mile or two from the fault, Lower Pliocene beds, presumably the approximate equivalent of the Ricardo formation exposed farther east, occupy a strip along the margin of the desert. Farther east, not far from the base of the Garlock scarp, rhyolite outcrops through the recent fanglomerate. South of Mohave is the type section of the Rosamond formation together with great thicknesses of both basic and acidic volcanics which may or may not be properly considered a part of the Rosamond. The Pliocene Warren beds are not found on the Tehachapi block north of the fault, and it is very doubtful if they were ever deposited on any part of it. The exact age of the type Rosamond is not known, but both it and the associated volcanics differ lithologically in many respects from the Middle Tertiary formations of the Tehachapi Mountains. It therefore appears that, as far as is at present known, the Tertiary formations of the Tehachapi Mountains are found only in that province and are limited desertward by the bounding Garlock fault; and the Tertiary formations of the contiguous Mohave Desert are likewise largely or wholly restricted to that district and are not encountered on the Tehachapi side of the fault. It is improbable that all these formations on both sides of the fault, some of them very thick, were very local or restricted in their original distribution.

The logical conclusion would seem to be that, though obviously the relief-producing movements on the Garlock fault have been Quaternary and Recent and perhaps late Plio-

cene in date, that line of dislocation must have been a locus of sharp deformation, cutting off formations or limiting the area of their deposition more or less repeatedly during earlier Tertiary times, and that the fault is hence an old rather than a very recent feature. This conclusion is of importance in any attempt to comprehend the Tertiary history of the southern Sierran and Mohave provinces.

San Gabriel Mountains front. Further study of the faulting along the south base of the San Gabriel Mountains east of Mount Wilson has corroborated a supposition mentioned in an earlier report, that although most of the fault surfaces appear to slope northward and under the uplifted mountain block, normal faults do occur. North of the town of Sierra Madre a reverse and a normal fault have been found in the same section in the lower part of the great scarp which overlooks the San Gabriel Valley. The reverse fault is at the south base of the scarp and the normal fault trace lies perhaps a half-mile north of it and up to 1000 feet above it on the scarp. The normal fault presumably meets the reverse fault a few thousands of feet below the surface. Rather sharp difference of opinion has existed among geologists in southern California as to whether the faults bounding the San Gabriel mountains on the south are normal or reverse, and certain quite different inferences have been drawn as to the mechanics involved in the uplift of the range. But most at least of the faults are steep, and it appears to the writer that the uplift, instead of being due primarily to horizontal forces, compressional or tensional, was much more probably caused by forces acting, near the surface at least, in vertical or steep directions.

STUDIES ON THE HISTORY AND EVOLUTION
OF WHALES
Remington Kellogg

Detailed studies of cetothere skulls in American and European museums have shown that fundamental structural details have not been critically enough evaluated by

cetologists. In some instances quite diverse types of cranial construction have been allocated to the same genus. The need for specific data pertaining to the significance of certain structural details became readily apparent. Accordingly, the illustrations of all previously described cetothere skulls have been photographed to a uniform scale. In addition, line drawings and photographs have been made for skulls heretofore unfigured. These uniform-scale photographs have been assembled in groups in accordance with the relationships of the cetotheres and their appearance in the geological time scale. The diverse types of cranial construction represented by these skulls will be studied to trace the steps in remodeling that led up to the Recent whalebone-whale types of crania and to elucidate the fundamental structural alterations that made possible the several lines of descent. This study will be supplemented by comparisons with fetal skulls of Recent mysticetes.

To Lieutenant W. L. Sutter, U. S. Coast Guard whaling inspector on the Western Operating Company's antarctic floating factory ship *Ulysses*, and to Chief Boatswain A. Van De Venter, stationed at the American Pacific Whaling Company's shore station at Akutan, Alaska, acknowledgment is made for their assistance in procuring skulls of several fetal whalebone whales for these studies.

During July 1939 and June 1940, the Miocene cliffs on the western shore of Chesapeake Bay were searched for additional cetothere remains. Skulls, mandibles, and other skeletal elements of *Siphonocetus priscus* and *Mesocetus siphunculus* were obtained.

Through the generous cooperation of Professor Alfredo Augusto de Oliveira Machado e Costa, Director of the Museu e Laboratório Mineralógico e Geológico, Universidade de Lisboa, and Professor Antonio Sousa Torres, Collaborator of the Serviços Geológicos de Portugal, measurements and photographs of the cetothere skulls described by Vandelli in 1831 from the Tortonian Miocene sands and clayey sandstones on the coast of Portugal at Adiça have been made available for these studies.

The relationships of fossil marine mammals and their importance for purposes of intercontinental geological correlation, as well as the effects of man's activities on the Recent species, were discussed in a paper entitled "Tertiary, Quaternary, and Recent marine mammals of South America and the West Indies," which was presented in the joint symposium held under the auspices of the biological and geological sections of the Eighth American Scientific Congress, held at Washington, D. C., in May 1940.

During the past year Mr. Sydney Prentice has prepared a number of illustrations of the Calvert Miocene cetotheres.

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STUDIES ON RELATION OF INVERTEBRATE
FAUNAS TO GEOLOGICAL HISTORY OF
JOHN DAY REGION OF OREGON

E. L. Packard

The Cretaceous of the Mitchell area. The cooperative mapping of the Mitchell quadrangle has been completed by Dr. Buwalda. Faunal field studies have been concentrated in those regions where stratigraphic sequences could be demonstrated, although collecting localities have been developed at places where the stratigraphic position within the exposed Cretaceous is not definitely known. Two brief trips, one by Mr. Alex Osanik, research assistant assigned to this project, have this year yielded additional geologic data, and collections for critical areas. A measured stratigraphic and faunal section was made.

The entire fauna has been studied in the laboratory and the determinations and descriptions of new species completed. It is planned to compare, as far as possible, all new forms with material now in Washington, the Philadelphia Academy of Science, and the Canadian Geological Survey collections at Ottawa during the early part of the summer of 1941. The final manuscript and plates will then be prepared for publication.

The Cretaceous rocks outcrop within the Mitchell quadrangle as a strip approximately 18 miles long and from 2 to 5 miles wide. These exposures trend in a northeasterly-southwesterly direction across the southeastern corner of the quadrangle, and extend beyond for a short distance into the adjoining Round Mountain quadrangle as mapped by W. D. Wilkinson and published by the Oregon Department of Geology and Mineral Industries. These massive sediments rest upon a metamorphic complex of schists, crystalline limestones, and greenstones of unknown age. They are probably represented along upper Rock Creek, and elsewhere at the foot of the Ochoco fault scarp and eastward to the South Fork of the John Day River. The Cretaceous also shows unconformable relations with the younger Clarno formation of Eocene age.

These late Mesozoic rocks have been deformed into a major anticlinal structure modified by several strike and cross faults. The most complete section occurs along Bridge Creek below Mitchell, where 4500 feet of shales, sandstones, and conglomerates are exposed on both limbs of an anticline, the axis of which trends about N. 50° E. with dips up to 40°. This type section of the Mitchell Cretaceous is divisible into four stratigraphic units, the lowest of which is composed predominantly of dark-colored shales, often concretionary and frequently fossiliferous. This member has a thickness of about 1800 feet. The second member, 620 feet thick, is composed of massive conglomerates, including much angular shale, schists, and occasional limestone pebbles. Overlying this nonfossiliferous conglomerate is 600 feet of shale indistinguishable from the lower shale and containing a few marine fossils. The uppermost member is a conglomerate about 300 feet thick, very similar to the lower conglomerate. The source of these coarser sediments must have been close at hand, in near-by areas of metamorphics or coarse sediments, including basal conglomerates of Jurassic, Triassic, or earlier formations such as are now exposed within the southern part of the Dayville quadrangle.

The lower shale member, or formation, has yielded a fauna rich in cephalopods, with lesser numbers of pelecypods, brachiopods, echinoids, and crustaceans. The vertebrate fauna includes an ichthyosaur and a specimen of pterosaur allied to *Pteranodon*. The ammonites include a number of wide-ranging and well-known species, such as *Gaudryceras sacya* Forbes, *Desmoceras voyi* Anderson, and a number of Californian species of *Sonneratia* previously found only in the upper Horsetown. A group of three new species of an ancylocerid type are assigned to a new genus. Desmocerids are the most common forms, and are found by the hundred in a rather restricted horizon traceable on both limbs of the Cretaceous structure, and for several miles along the strike. This group includes at least three new species. Eight species of the genus *Sonneratia* are found, of which three are considered new. Large lytocerids are present in the fauna, as are two new species of *Pervinquia* and a new species of *Tetragonites*. The twenty or more new species, together with the previously described species of the fauna, indicate that the lower shale fauna is most closely allied to the middle and upper Horsetown of California.

The Dayville quadrangle. Dr. Charles Merriam and Mr. John C. Reed restudied the Paleozoic fossil plant beds of the Dayville quadrangle and procured extensive collections which are now being examined in the East.

Mapping outside the Dayville by Dr. W. D. Wilkinson and three graduate students has carried the formations outcropping within the Dayville area westward across two adjoining quadrangles, as yet unmapped topographically. It has thus been possible to connect the geological map of Deschutes Valley by Dr. Hodge, which has already been published, with the Dayville, and thereby determine the stratigraphic relations between the Madras formation and the Neocene sediments and rhyolites of the Paulina Basin. This mapping program, involving only the Tertiary rocks as exposed in the Round Mountain quadrangle south of Mitchell, has led to the publication of a geologic map by the Oregon State Department of Geology and

Mineral Industries, as prepared by Dr. Wilkinson.

The detailed mapping of the Tertiary of the Dayville quadrangle has been completed. The boundaries of Cretaceous, Jurassic, and Triassic systems and the Paleozoic are drawn; but, except for the upper Cretaceous, the subdivisions cannot yet be made, owing to the lack of faunal control, especially in the Jurassic and Paleozoic. Dr. Ralph Luper recognizes several stratigraphic divisions within the Jurassic system, but as yet they have not been plotted. The Triassic rocks include two Upper Triassic faunas, recognized by Mr. Edward Schenck, now National Park Service geologist located at Boulder Dam. The discovery of Permian rocks within the Paleozoic area will require differentiation into two or more formations, which, in such complicated structures as prevail, can only be made after close faunal studies. It thus appears necessary to postpone publication of the Dayville map until faunal studies can be made, or to publish a map in which the Jurassic at least would appear as undifferentiated. A manuscript is being prepared on such a basis.

The Tertiary formations include the Clarno, John Day, and Columbia River Lava, the Shaw and Harney (MS names), and a late Tertiary or Quaternary andesite. These have all been studied in detail except the fauna of the Shaw, which Mr. Stirton has examined and recognizes as Neocene of two possible stages. The beds in which these vertebrates occur include but a single stratigraphic unit.

PALEOBOTANICAL STUDIES IN OREGON

Ralph W. Chaney

The scarcity of plant remains in beds of Pliocene age has been an obstacle to our understanding of the great floristic changes which took place in eastern Oregon at the end of Miocene time. Modern forests lack the redwood and many of the broad-leaved deciduous genera which characterized the Miocene, and major changes in topography and climate appear to have been involved in

their elimination from the John Day Basin and adjacent areas. Recent studies of the Pliocene Dalles flora, and of the related Troutdale flora on the western side of the Cascades, tend to fill in this gap in the history of vegetation. They indicate that as the Cascades were raised during later Tertiary time, the redwood and other plants were restricted to coastal areas where a moist equable climate persisted. Continuing studies of Pliocene floras in Oregon and to the south may be expected to add many additional details regarding the geologic and floristic history of western North America.

The resemblance of the Miocene plants of Shantung Province, China, to those of the same age in the John Day Basin has already been noted in part I of the Shanwang flora (Carnegie Inst. Wash. Pub. No. 507). The completion of this study has emphasized the general resemblance of the later Miocene floras on both sides of the Pacific, and indicates also that there were already developing certain of the floristic differences which now characterize the forests of China and Oregon.

Preliminary field studies in Harney County, which lies to the south of the John Day Basin, indicate the presence there of Tertiary volcanics and volcanic sediments which correspond closely to those studied elsewhere in eastern Oregon. A Miocene flora of the Mascall type has already been collected, and there is reason to believe that future field work will yield floras similar to those found in other stratigraphic units of the John Day Basin.

STUDIES ON THE HISTORY OF GRAND CANYON PALEOZOIC FORMATIONS

Edwin D. McKee

Investigation of the Paleozoic formations of Grand Canyon has been continued with further accumulation of field data and with a considerable amount of laboratory study on specimens previously collected. The principal objective of this investigation—the demonstration of the character of changes in lithology and fauna in a lateral as well as in a vertical direction—appears to have sufficient

significance to justify the degree of detailed study which is being made. Already several important principles of stratigraphy have been demonstrated and clarified through the application of detailed studies in the Grand Canyon, where exceptional opportunities for such work are offered by the continuous exposures of undisturbed strata.

Studies involving the Cambrian, Devonian, and Permian strata of Grand Canyon were carried on more or less simultaneously, but special emphasis was given to the Cambrian problem in an effort to complete the initial investigation of it this year. It is planned that a description of the fauna will be given by Dr. Charles E. Resser, accompanied by a discussion of the stratigraphic relationships and their significance by McKee. Among the interesting features to be brought out are (1) evidence that formation boundaries in the Cambrian strata of Grand Canyon do not coincide with the time lines, but cut across them; (2) demonstration of constant direction from east to west, unaffected materially by the presence of islands, during deposition of the basal sandstone formation; (3) evidence that facies rather than age differences are major factors in accounting for certain Middle Cambrian faunal assemblages; and (4) data indicating that green shales, glauconite-iron zones, primary dolomites, and limestones may represent a lateral sequence of deposits formed under varying environments during any particular period of deposition.

Studies of the deltaic deposits of the Supai and Hermit formations of Permian age suggest that the basal part of the Supai is of progressively greater age as followed from east to west, or toward the Nevada geosyncline, where deposition was more rapid and continuous during all of Paleozoic time. It now seems probable from a preliminary study of the faunas that the basal beds as found in western Grand Canyon are of Pennsylvanian rather than Permian age. Another type of study, consisting of a detailed lateral tracing of individual beds, should throw light on the rate of sedimentation on the delta surface.

Permian deposits of the Arizona-Utah

*basin.*¹ Paleozoic seas advancing eastward into the Arizona-Utah basin extended at no time farther than the eastern limits of these states, although some continental sediments were deposited in the area beyond. The southern limits of the basin were also clearly defined, for in central Arizona there is a granitic positive element, called Mazatzal land, which successfully separated most of the corresponding faunas and sediments of northern and southern Arizona during the Paleozoic. On the other hand, even though some of the clastic sediments deposited in the basin were derived from the north, its boundaries in that direction are not well known because of a lack of exposures in central Utah. In this Arizona-Utah basin, by far the greatest accumulation of sediments was during the Permian period, when strata 2500 feet thick, both continental and marine, were laid down, leaving a record which today is beautifully exposed in the walls of Grand Canyon and other canyons of the plateau region.

In the classic Grand Canyon section and elsewhere throughout a wide area, the Permian formations, from bottom to top, consist, first, of two series of red beds of deltaic origin; next, of an aeolian sandstone; and, finally, of two series of cyclic deposits which are largely of marine origin. Detailed studies of all five of these major subdivisions have been undertaken with a view toward demonstrating the nature of both the vertical and the lateral changes within and between them, of emphasizing the principal contrasts resulting from the different types of environment which they represent, and of determining criteria for the recognition of each. These studies have consisted chiefly of a detailed tracing of beds by means of carefully measured sections and of statistical analyses of cross-lamination patterns in various units. They have been supplemented in certain critical horizons and localities by mechanical and chemical analyses, by examination of thin sections and polished surfaces, and by paleontological studies.

¹ Reprinted partial abstract from Trans. New York Acad. Sci., ser. 2, vol. 2, pp. 153-155 (1940).

In the two red-bed formations which make up the lower part of the Permian section, it has been possible to demonstrate through detailed studies of the cross-lamination many features regarding the directions of movements among the sediments and concerning the general character of deposition on the delta surfaces. A measure of the rapidity of delta growth has been ascertained by detailed examination of the cyclic character of the sediments; data on the nature of lateral changes toward marine facies have been obtained through the tracing of beds. On these latter problems much remains to be done.

The aeolian sandstone in the middle of the section provides an excellent example of a desert dune deposit, and makes possible an especially interesting comparison with formations representing other sand environments. The general character of the dunes and the regional direction of their movement have been determined, and data have been obtained which help to differentiate this type of deposit from analogous ones.

The two uppermost formations are different in many details, but both are composed of varied types of sediment which were deposited during the stages of an advancing and retreating sea. Furthermore, it is possible to subdivide each of these formations into natural lateral units or facies based on observable changes in fauna and lithology. Special attention has been given the distribution—in relation to facies and horizons—of gypsum deposits and of both bedded and nodular chert, and it has been found that most evidence favors a primary origin in each case. The distribution of the magnesium content in the limestones also suggests a relation with the environment of deposition.

The Permian basin deposits of northern Arizona offer exceptional opportunities for detailed work, both because of the unique character of the exposures and because of the contrasts in the types that are represented. This work should serve to demonstrate many of the principles of stratigraphy and sedimentation for which material is less completely available in other regions.

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STUDY OF PLEISTOCENE LAKES OF SOUTH CENTRAL OREGON

Ira S. Allison

An investigation of the Pleistocene lakes of south central Oregon was conducted during the field season of 1939 by Dr. Allison, with the assistance of three students from Oregon State College. Dr. W. D. Smith, of the University of Oregon, visited the party in the field for a few days, and Dr. Daniel Axelrod, paleobotanist, accompanied the party for ten days to search for possible plant remains.

On the basis of a preliminary reconnaissance made over the area from the vicinity of Fort Rock and Lakeview, Oregon, on the west, to Catlow and Alvord basins, Oregon, on the east, it was decided to concentrate detailed work on the Chewaucan-Summer Lake basin near Paisley, Oregon, and the Silver Lake-Fort Rock-Christmas Lake-Fossil Lake basin, in order that the studies might be integrated with the archaeological studies being carried on by Dr. Cressman.

Special attention was given to the shore features of the former high-level lakes in order to determine their upper limits and their areal boundaries. Many miles of shore line were traced out, a fan delta at Paisley was mapped in considerable detail, and outstanding features were photographed. Most detail was obtained on the greater Fort Rock basin, partly on account of the wave-cut cave in Nigger Hill on the Menkenmaier ranch, which cave was occupied by early man, and partly on account of the occurrence of abundant mammalian fossils at Fossil Lake in the eastern part of the basin. A quantity of additional bones was collected.

Whereas the paleontological evidence favored an early Pleistocene age for the Fossil Lake deposits, the geological evidence appeared to favor a late Pleistocene age. It was

suggested that the fossils are related to an early Wisconsin stage in a sequence of two Wisconsin high-water stages, equivalent to Tahoe and Tioga glacial stages in California and similar stages in the mountains of Oregon and Washington. The dating of the lakes and their deposits is especially important in establishing the time relations of the wave-cut caves and their enclosed archaeological materials.

This study was continued during the field season of 1940. The field work was confined to the Fort Rock-Christmas Lake valley with a view to completing so far as possible the study of one major lake basin. The work was greatly facilitated by aerial photographs on a scale of 1 to 20,000, made available by the Soil Conservation Service, U. S. Department of Agriculture, which had the entire basin photographed in 1939. With the aid of these pictures the greater part of the shore line around the basin was traced out with comparative ease, and of course the pictures were of value in many other ways. The shoreline studies were controlled by tens of miles of levels that were run within the basin to supplement the limited number and uneven distribution of bench marks within the area.

In the field studies of 1940, three subjects besides the shore-line traverses received special consideration: (1) the fossil-bearing beds at Fossil Lake, (2) sections of lake beds exposed in wind-cut basins on the floor of former Fort Rock Lake, and (3) the outlet of the lake.

At Fossil Lake several pits and trenches were dug in the lake beds to get fresh exposures. Detailed measurements and photographs were made, and an extensive set of samples of the sediments was collected for later laboratory studies. The principal outcome of these detailed investigations was the revelation that the principal mammal-bone horizon is a thin zone of disturbed shallow-water sediments lying between the main mass of somewhat compact, more or less uniform lake beds of pumiceous sand and silt below, and a less compact, friable complex of pebbly and even bouldery basalt sand, pumicite, and lake silts above. The sediments associated

with the mammal fossils include intraformational conglomerates, including flat pebbles of the underlying lake beds, and hence indicate water not more than a few feet deep at the time of their formation. The presence of horses, elephants, camels, etc. out in the middle of the lake basin is therefore no longer a problem, as the sediments indicate that the lake level must already have declined by more than 200 feet. The mammal-bearing beds are succeeded by others in which fossil birds and fossil fish (including large forms, probably salmon) are common. The time value of the low-water stage is uncertain, but it is thought to have been too short to be the equivalent of the gap between Tahoe and Tioga glacial stages. At any rate, the lake did not dry up enough to kill off the fish fauna in the interim. On the whole, the data seem to show that the mammalian fauna is associated with a low-water stage near the close of the lake's history and hence is late Pleistocene or early Recent in age.

Additional bones and teeth were collected, including, among the mammals, horses, elephants, camel, bison, rodents, cats, wolves, and probably several other forms. Fish bones or fragments number in the hundreds. They include a few nice jaws showing dentition. A few hundred bird bones were obtained, ranging through a considerable variety which appears to include eagle, hawk, owl, geese, ducks, flamingo, etc. It is not unlikely that these collections contain species not heretofore found or described at Fossil Lake.

In the west central part of the Fort Rock Lake basin, east of the Connley Hills and 15 to 20 miles southeast of Fort Rock, the wind has excavated several basins in the bed of the former lake. These attain lengths of $\frac{1}{4}$ to $\frac{1}{2}$ mile and depths of 50 feet or more, and hence afford good sections of the lake beds. The sides of such basins were freshened by digging so as to permit measurement and to get photographs of the beds. One such basin is traversed by one large sand dike and several lesser ones. Another, called Arrow Sink, furnished a fine succession of lake beds capped by a Recent fan that included a bed of pumice which is correlated with the post-

lacustrine sheet of pumice that occurs over most of the area, so that a fairly complete and continuous sedimentary record is had of late Pleistocene and Recent time. This was measured and plotted very carefully, as it is thought to be unusually important in the local chronology.

Further search for the former outlet of Fort Rock Lake (through which the anadromous salmon could reach Fossil Lake) determined that it is now buried by postlacustrine lava flows to a depth of more than 100 feet. These lavas, issuing from Lava Craters on the south slope of Newberry Crater, spread fanwise so as to cover the northwestern part of the lake basin and to bank up against the older buttes and plateau lavas along a front more than 20 miles wide. The outlet must lie beneath these lavas. On the distal side an abandoned river channel extends from a point near Moffitt Butte along a northerly course to join the Deschutes River near Lapine, Oregon. Part of this channel is shown as "Long Prairie" on the Maiden Peak topographic sheet, U. S. Geological Survey.

Field work at Lower Klamath Lake basin, California. Dr. Allison was associated with Drs. L. S. Cressman, Ernst Antevs, and W. D. Smith in a field study of Lower Klamath Lake basin, California, in the summer of 1940. The findings of this study are covered in the reports of Drs. Cressman and Antevs.

STUDIES ON EARLY MAN IN SOUTH CENTRAL OREGON

L. S. Cressman

This report has four divisions: (1) field trip with Dr. E. B. Howard; (2) examination of the Prospect (Medford-Crater Lake Highway) skeleton locality with Dr. Howell Williams; (3) further examination of Five-Mile Point Cave 3 at Paisley; and (4) summer field work, 1940, in the Lower Klamath Lake basin.

Field trip with Dr. E. B. Howard. Dr. E. B. Howard accompanied Cressman in an examination of the proposed Lower Klamath Lake area and the sites excavated west of

Steens Mountain, including Catlow Cave 1, Roaring Springs Cave, the Summer Lake caves 5 miles from Paisley, and the Fort Rock Cave. It was Dr. Howard's opinion that the Lower Klamath Lake locality was one of considerable promise and apparently similar in many ways to the Clovis area.

Examination of the Prospect (Medford-Crater Lake Highway) skeleton locality. Dr. Howell Williams and Cressman examined the locality near the Flounce Rock Ranch on the Medford-Crater Lake Highway where the skeleton had been dug up by the highway crew this spring. Cressman had previously examined this locality with Dr. W. D. Smith, of the Department of Geology of the University of Oregon, and J. G. Bromley, maintenance engineer of the State Highway Department for this division. Mr. Bromley had had men examine certain depressions in the pumice above the road cut to determine if these might have been caused by ground caving in over burials or if they were the remains of house pits. He reported that there was no evidence of either, and so the inference is that they were depressions caused by overturned trees which had long since disappeared.

The exact location at which an earlier skeleton was found is uncertain, but it is entirely probable that it was found in the same road cut as the 1940 one.

This last skeleton was found under 6 feet of pumice. It lay in a crumpled position, on its face, with the top of the skull facing down the river. There was no order to the bones, nor were any artifacts found with them. The skeleton is in an excellent state of preservation, probably owing to the protection afforded by the heavy overburden of pumice. The position of the body argues against a burial, as does the lack of artifacts, although neither of these, of course, is proof in itself. The depth of the pumice covering the body also argues against aboriginal burial.

The pumice in this cut overlies badly weathered tuff. The formation dips sharply to a maximum depth at the center of the cut and rises at the south side, so that the body rested almost in the center or at the

deepest point of the trough. The excavation was continued to the hard weathered pumice immediately over the tuff, a distance of about 3 feet.

Arrangements have been made with Dr. Theodore D. McCown, of the Department of Anthropology, University of California, to examine the skeleton and prepare a report. It is Cressman's opinion that this skeleton represents the remains of a victim of the pumice eruption which occurred during the formation of Crater Lake.

Paisley Five-Mile Point Cave 3. Cressman with two assistants spent several days continuing the excavation of Paisley Five-Mile Point Cave 3, in which the test pit of 1939 showed association of extinct fauna (horse, camel, bison, etc.) and human occupation in the form of fire lenses, a fragment of obsidian knife, a fragment of worked obsidian, and long bones broken for their marrow. The excavation confirmed the evidence from 1939 by producing more fragments of worked obsidian associated with more fossil bones, which have not as yet been identified. Ash and charcoal are associated with the bones and the artifacts. The locality was evidently a camp site where the occupants of the cave sat about on large water-smoothed rocks which formed the floor of the cave, built their fires in a semicircular depression formed by the water-smoothed boulders against the rear wall of the cave, about 7 feet below the present surface, and threw into the pit the bones of the animals which they cooked and ate there. The association of the fossil fauna and the human occupation is clearly verified.

The stratigraphic series in this cave runs roughly as follows, reading from the present surface at the point over the deposit of bones and artifacts: (1) 18 to 24 inches of cave debris with fire lenses of temporary camping parties but lacking artifacts; (2) 18 to 24 inches of pumice, apparently from Crater Lake; (3) 36 to 48 inches of rather fine dust and fragmental materials from the cave walls, in the lower 12 inches of which were the faunal remains, artifacts, and fire lenses; and (4) sand and gravels on the floor of the cave.

This stratigraphic series would suggest

that the eruption of Mount Mazama occurred sometime in the dry period between 7500 and 4000 years ago. It is suggested that this period must have been long enough for the 24 to 36 inches of sterile deposit to form between the abandonment of the shelter and the pumice shower. Some of the deposit is aeolian and some is apparently eroded from the cave wall, so that no estimate of the lapse of time necessary for the deposition is possible, nor can we say when, in the time preceding the arid period, the hunters and extinct mammals lived.

Summer field work, 1940, in Lower Klamath Lake basin. The problem at Lower Klamath Lake fell into two parts: (a) examination of the association of artifacts with the fossil fauna to determine whether the association was original or derivative, and (b) a study of the character of the human occupation of the lake to discover, first, the number and character of horizons represented; second, variations, if any, in these horizons in different parts of the lake; and, third, the general chronological sequence of the horizon or horizons represented.

Method of study: To test the association of artifacts and fossil fauna, since all evidence up to this time had consisted of surface materials which might have been dropped as a result of erosion of superimposed beds, it was necessary to trench undisturbed deposits in order to discover if the association occurred there. Dr. Ernst Antevs, Dr. Ira Allison, and Dr. W. D. Smith were invited to assist in working out the geological and chronological history of the lake bed. Two lines of approach were used: study of the geological features of the lake basin, and study of the evidences of climatic change as reflected in the beaches.

The trenching was carried out in three major localities, selected because of the occurrence of associated fossil fauna and artifacts and the erosion of artifacts, especially campfires and rubbing stones, from a considerable depth under the original surface. The excellent collection of Mr. Frank A. Payne, of Klamath Falls, was also put at our disposal, and generous contributions to the Oregon State Museum of Anthropology in the Ore-

gon Museum of Natural History of the University of Oregon were made by him to assist in the study of this problem. Mr. C. B. Howe, a schoolteacher from near Klamath Falls, has also contributed material and information which corroborates that of Mr. Payne.

History of the problem: Lower Klamath Lake was formed by backwater which drained into it about 2 miles above the beginning of the Klamath Gorge, the outlet for Upper Klamath Lake. The lake bed, until the entrance was dammed about 1917 by the Bureau of Reclamation, was a vast bed of tules with a narrow channel extending the length of the lake. Peat formed rapidly where the tules grew, and large sections broke off and were known as "floating islands," drifting about before the wind. The "channel,"¹ however, was always clear of weeds and was used by steamboats until about 1907. A few years after the lake was drained, in 1917, the peat dried out and was set afire. Following the fire, which burned for several years, the high winds blew the ash and much of the exposed underlying unburned peat and lake deposits away, exposing new surfaces over large areas of the lake bed. As this exposure of new surfaces took place, Mr. Payne, who was building up a collection of "relics," began to collect from the area and has continued to do so for the past ten years. He collected carefully and kept his material well segregated by localities. Some two years ago he became convinced that a number of horizons of culture were represented in his materials and that the earliest was probably associated with the fossil fauna, which is found along the old "channel," and, to the best of present knowledge, only there. He eventually brought this to the attention of the Department of Anthropology at the University, and put all his experience, materials,

¹ The word "channel" is used here in a special sense. There really was no channel in the lake, since it had no outlet, but only what might be spoken of as currents formed by pressure from the Upper Klamath Lake source, wind action, and differential levels of the lake bed. That there was gentle current action is shown by ripple marks in the very hard sand bed and the cross-bedding in some of the trenches dug at the Narrows.

and knowledge at the Department's disposal. Whatever success may have been attained in arriving at an interpretation of the history of this area is primarily due to the completely unselfish attitude and the active cooperation of Mr. and Mrs. Payne.

Analysis of results: An analysis of results at this time must, of course, be in the nature of a preliminary report, since the detailed analysis from the study of materials has not yet been made. However, certain very general statements may be made, giving the present status of the problem.

a) Association of fossil fauna and artifacts at the Narrows and the Cove: In the portion of the lake called the Narrows, about a mile south of the Oregon-California line, marked by the old "channel," a surface is exposed which underlies the low-grade peat characteristic of the deposits beginning just under the recent peat and continuing in some places as much as 3 feet. These exposed yellow beds are in some places interbedded with sand strata, and differ in that way from localities lying outside the "channel." This area otherwise seems to be little different from the characteristic deeper lake deposits in other parts of the lake bed. When thrown out and exposed to the sun, these deposits dry out to a whitish color with a kind of varve appearance. There is represented here, according to Antevs, a characteristic gyttja, or excrement of worms and other low forms of organic life.

This bed was covered in various places outside the immediate "channel" by uneroded prominences in most cases not over 6 inches in height, although according to Payne they were formerly more marked. These prominences were blue-gray in color and were the remains of the lower peat bed, with which much diatomaceous and other material such as volcanic ash was mixed. All the material found on the surface in the "channel" seemed to have come from these blue-gray prominences as they have been eroded. Bone artifacts and fossil materials all have the characteristic blue-gray color, whereas materials coming from the top of the yellow beds have a very characteristic yellow discoloration,

sometimes even a marked impregnation of reddish brown or iron. The yellowish color of these exposed beds Dr. Allison thinks is due simply to the greater amount of oxidation which has taken place as a result of their exposure.

A series of trenches cut in the yellow beds did not reveal a single fossil mammal specimen, although the places in which digging was carried out were those where the surface had the largest accumulation of fossil remains. Fossil fish remains, however, were common.

The same methods were then applied to the blue-gray prominences, to discover, if possible, evidence of the association of fossil fauna and artifacts. We have no absolutely reliable evidence from this digging that the association was original. Certain facts, however, are suggestive. The most specific evidence that we have consists of a fragment of a projectile point and a scraper from the bottom of one of these prominences, and a large number of pieces of fossil ivory from the same place. The two artifacts were loosened by trowel and were obviously in an undisturbed situation. The same is true of the ivory, which represents fragments of tusks of some species of elephant, some of whose remains were found scattered about this general locality. Neither of the artifacts apparently shows sand-blasting.

There seems no evidence whatsoever that the fossil mammal remains come from below the blue-gray deposit represented in the prominences. A large bone, probably a part of the elephant skeleton, was found projecting down into the yellow bed from the blue-gray, but it was on end and could easily have sunk into the soft mud under it. The same is true of the large articular surface of a long bone of elephant, found close by the locality under discussion.

The observations made by Payne have a very definite bearing upon this problem. The ordinary method of collecting in these basins is to work over an area, picking up all the material so that the surface is practically cleaned so far as artifacts go; then, after one of the "blows" which carry off enormous quantities of dust and sand, to go again to

the same area, where more specimens will be found, having been uncovered by the wind. In ordinary dune country this would have no significance, since covering and uncovering of the same place would occur any number of times, as it does in spots in the Lower Klamath basin. No competent observer, however, will confuse dune material or drift sand with undisturbed lake deposits. In this case Cressman verified Payne's experience and found materials exposed after a dust storm in an area which had been picked clean shortly before; and these came from a fairly hard, undisturbed surface.

Payne constantly asserted that the fossilized bone artifacts and points characteristic of the Narrows, and apparently the fossil bones, came from the uneroded blue-gray mounds in both the Narrows and the Cove. He recounted a number of instances in which fragments of bone artifacts had been exposed in the sides of one of these blue-gray mounds, and by careful searching the whole piece was found within the undisturbed part of the mound. These observations were confirmed by our experience in the field. Those specimens which have been uncovered and exposed to wind all show marked sand-blasting, a feature lacking in those newly exposed.

It is Cressman's very definite opinion that the fossil mammal bones and the artifacts represent an original association, although he states frankly that we do not have any proof beyond the one association referred to above. Careful consideration of all the possibilities leads to the conclusion that such an association could not have been derivative. The only conclusion that can be drawn is that the artifacts were there when the mammals came into this part of the lake to feed and drink. That this is possible, we know from the evidence of the Paisley caves, where a late Pleistocene or early Recent fauna is associated with human remains.

Excavations at the extreme south end of the "channel" (which we named the Cove), from which Payne had secured a number of long bone foreshafts very much like those found by Howard at Clovis, were completely negative. Cressman had previously found in this

locality a Folsom-shaped point in an advanced stage of weathering. It lacked the characteristic Folsom channel flaking.

Excavations in the area to the north along the "channel," as well as to the south, were extremely difficult this year because of the greater precipitation, which had produced a very lush crop of wild mustard, foxtail, and nettles over places completely lacking any vegetation a year ago. These weeds held much sand that had drifted last fall and early winter, and many possible areas were thus completely hidden. In these two areas, not less than forty different "digs" were carried out.

b) Laird's Bay, south end of lake: This locality extends about a mile, with old camp sites exposed along perhaps a quarter of the distance. Many stones were also exposed here which had perhaps been ice-rafted from the cliffs on the west side. This locality was on the lake side of the farthest extension of the recent peat beds, which are still to be seen in some places at the south end. It was also close to the "channel." The sediments here are significant and occur in the following order: About 3 feet of recent peat remains, of the original deposit of from 6 to 8 feet; under this occurs several feet of low-grade peat mixed with inorganic matter as well as invertebrates and probably large numbers of diatoms; under this occurs gyttja and probably some organic plant remains to water level. These profiles were taken at the edge of the peat bank. Complete details will be given in the final report.

The camp sites which are being exposed by erosion are found in some places close in to the peat bank, but mostly at some slight distance out, up to 100 yards or more. It is significant that they occur in the low-grade peat deposits. Trenches dug here show clearly that the artifacts were weathering out of these beds and not dropping from above, a good number of specimens being found *in situ*. No fossil fauna were found *in situ*, although a number of unidentifiable pieces were found on the surface. We cannot be certain whether these weathered out or were dropped there by some collector who had brought them

from another area. The former possibility is likely, since some shattered fragments were found apparently weathering out. It is with special reference to the artifacts from this locality, which were definitely *in situ*, that the study of climatological evidence would seem to have bearing.

c) Artifacts: The artifacts found and those previously collected by Payne tend to indicate that three cultural horizons are represented in the series from the lake. The first, apparently associated with an extinct fauna, is represented by the very crude projectile points, willow leaf in shape, with one surface flat and the opposite having a high dorsal ridge, and by the beveled-edge knives, much weathered grinding stones, and fossilized bone foreshafts, characteristic of the Narrows and the Cove. The second is represented by the Laird's Bay materials. This horizon lacks the fossilized bone foreshafts, and has fewer of the crude projectile points than occur at the Narrows. A type of heavy projectile point with a straight butt and side notches makes up a greater percentage of all points at Laird's Bay than at the Narrows and the Cove. Fossilized bone awls occur in all three localities. Mortars were found at the Narrows and Laird's Bay, but it is not certain that they belonged to the former locality.

The third horizon is represented by historically modern materials from the surface around the shores of the lake and from the tops of islands in the lake proper. These points are all much smaller and much better made, frequently with barbs and corner notches, in striking contrast with specimens from the earlier horizon. Manos are found in all three horizons, and mortars and pestles in the second and third. Antler wedges, pipes, shell beads, and bone awls are also found in the third. No pipes have, to the best of Cressman's knowledge, ever been found in the first two horizons. Though some artifacts appear in all horizons, the predominance of types characteristic of each horizon is clearly marked.

This distribution of types indicates that the people who used the artifacts lived at times when the lake conditions were quite different.

The grinding stones, scrapers, and awls found in the Narrows must have been used when there was little or no water there, probably just a slough, as was also the case at the Cove and Laird's Bay. The recent horizon represents a life lived about the shores of the lake when it had reached the level which characterized it down to 1917. The occupation of the islands was, of course, possible by the use of dugout canoes, which are known historically and remains of which are occasionally found today embedded in the peat.

Inferences on chronology: Any chronological observations must depend on the pertinence of the geological and climatological evidence. See report of Dr. Antevs. If the theory of climatic change, with the lake level responsive to the changes, is a true explanation, then we can fit this material into a significant chronological scheme. It would run roughly as follows: The horizons represented by the material associated with the fossil fauna would come from a period toward the end of the last pluvial, or something before 7500 years ago. This earlier horizon is represented by materials from the Narrows and the Cove.

The second horizon, represented by the Laird's Bay material, is correlated with the beginning of the Little Pluvial. The nature of the deposits covering the cultural remains in Laird's Bay appears to indicate that they represent an occupation considerably later than that of the Narrows and the Cove, and come from a period before the lake filled again at the Little Pluvial, about 4000 years ago.

If our theory is correct concerning the nature of the life of this lake and the human occupation, it is quite possible that there always was a small slough, even during the dry period. On the other hand, the lake may have dried completely, and water would have appeared again only when Upper Klamath Lake rose at the Little Pluvial. Occupation could have started and would have gone on at this point during the periods of variation in the water level and until the rising water prevented further use of the lake bed. There is no reason to believe that, once the lake was

filled at the Little Pluvial, it ever fell materially below the water level represented by the shore line which existed when the inlet was closed and the lake permanently dried in 1917.

The recent or third horizon, represented by materials found around the historic shore line and on the exposed islands among the tules in the lake, would represent a culture within the period when the level of the Little Pluvial lake was reduced to the modern water level, perhaps approximately from the beginning of the Christian era to the present.

Further evidence bearing on the interpretation of the climatic sequences represented here will be provided by analyses of the peat and of the possible changes in the forms of invertebrate life, reflecting the types of climate to which they were adapted. The study of pollen profiles and their significance for climatological changes is being carried out by Dr. Henry P. Hansen, of the Oregon State College.

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STUDIES IN PAST CLIMATIC VARIATIONS AND THEIR CORRELATIONS

Ernst Antevs

Dr. Antevs has compiled and analyzed observations on the major climatic variations in the Southwest since the culmination of the last Glacio-pluvial. The same major climatic variations, recorded by deposition and erosion by streams, rise and fall of lake levels, etc., have now been observed in so widely separated parts of the Southwest that they may have embraced the entire area. Dr. F. E. Matthes ("Report of Committee on Glaciers," *Transactions of the American Geophysical Union*, pp. 518-523, 1939) has found that the glaciers in the western mountains have under-

gone variations that parallel those of the adjacent desert lakes. Thus, the majority of the ice-age glaciers totally disappeared during the Postglacial; and the existing glaciers represent a new generation of ice bodies that came into being only a few thousand years ago. The amount of salts in some sink lakes is so small that, at the present rate, it would accumulate in some 4000 years. Therefore the pluvial lakes of these basins must have dried, and their salts must have been removed by the wind or been buried, before the modern lakes came into existence, about 2000 B.C. This date of a change from dry to somewhat moist climate, a change caused in large part by a fall in the summer temperature, was thus contemporaneous with a well-known temperature drop about 2000 B.C. in eastern North America and in Europe. This supports the view that the major changes in summer temperature affect the entire northern hemisphere, and it gives direct basis for a correlation of the climatic variations in the Southwest with the dated temperature variations in eastern North America and in Europe. Thus the dates of the changes in the latter regions can be roughly applied to the Southwest.

The pluvials of the Southwest and the extensive glaciations in the western mountains were genetically related to the continental glaciations in western Canada and adjacent United States, but were little influenced by the distant Labradorian ice sheets. The last or Provo Pluvial, which was notably cooler and moister than the present, prevailed perhaps from 35,000 to 10,000 years ago and culminated 23,000 to 20,000 years ago.

The Postpluvial may, on the basis of the major climatic variations, be divided into: (1) Early Postpluvial (8000-5500 B.C.). Climate at the beginning as today, but getting warmer and drier. (2) Middle Postpluvial (5500-2000 B.C.). Warmer and drier than at present. (3) Late Postpluvial (since 2000 B.C.). Especially in the first half, moderately moist; but Pyramid Lake, Nevada, failed to rise 50 feet above its highest modern level, attained in 1869, whereas pluvial Lake Lahontan reached 500 feet higher.

During all these ages there were surely climatic variations of smaller amplitude and shorter duration. Records are, of course, preserved especially of fluctuations during the Late Postpluvial. In the semiarid regions the streams have usually built up their beds during the moist ages and eroded them during the dry ages. Thus, there are valley fills from the Pluvial, the early part of the Late Postpluvial, and two or more from the Christian era.

AGE OF ARTIFACTS BELOW PEAT BED IN LOWER KLAMATH LAKE, CALIFORNIA

Ernst Antevs

For some years Mr. Payne has been finding stone artifacts in the wind-eroded floor of the former Lower Klamath Lake, California, in a stratum underlying remains of a peat bed. In 1940 Dr. L. S. Cressman and his students sank several pits in the lake deposits and exposed artifacts *in situ*. The excavations were made several hundred feet off the historic shore, about 2 miles northeast of the southern tip of the former lake and 8 miles south of the Oregon line, in section 25, T. 47 N., R. 2 E. With the purpose of dating the artifacts, a geological reconnaissance was made of the region by Dr. Warren D. Smith, Dr. Ira S. Allison, Dr. Cressman, and Dr. Antevs.

A typical profile of the lake beds, exposed by Dr. Cressman, showed, from top to bottom:

- d) 2½ feet pure brown fibrous peat.
- c) 2½ feet "silty" peat or peaty "silt" with solitary snails. In the upper 2 feet of this bed there are stone artifacts.
- b) 21 inches "silty" gyttja with numerous snails. The sediment dries to a gray-white color. It is very light.
- a) 10 inches sand and "silt" with organic matter. Bottom of pit, water level.

The "silt" may be a mixture of volcanic ash, pumice, diatomite, etc. The pure peat has blown away for the most part, but the silty peat, which is much more resistant, forms the ground surface over a large area. The pure peat is composed of tule (*Scirpus*)

roots, and remains of other swamp and water plants. It may have been formed in shallow water and in a tule swamp bordering open water, that is, under conditions similar to those that now prevail on the east side of Klamath River 10 miles south of Klamath Falls. The peat was forming until a few decades ago. Lower Klamath Lake was largely dependent on water from Klamath River, and has practically disappeared since an embankment was thrown up in the year 1917, preventing river water from flowing into the basin.

From 2½ to 4 miles northeast of the south end of the former Lower Klamath Lake, or in sections 19 and 20, T. 47 N., R. 3 E., there is a beautiful abandoned shore line. In places it is distinct because the fine debris has been washed out of the talus in the shore line and has been deposited just below it. In embayments there are bluffs, 2 to 3 feet high, cut in small fans. These bluffs are scarred by rills, but are otherwise very fresh-looking. In section 20 at B.M. 4088.9 this shore line stands at 4086 feet. The shore stands 7½ feet above the historic beach, and some 15 feet above the meander line of 1917.

About 2 miles farther to the northeast, or in the southeast corner of section 10, there is a curved spit extending northeastward partly across a bay. About ¼ mile from the southwest end there is a partial breach, 500 feet wide but only 6 feet deep. The spit is then preserved at its full height for another 250 feet, whereupon it ends abruptly with a steep bluff, 25 feet high, sharpened by a temporary modern stream. The spit is 400 feet wide. The surface material is ash-gray silt, perhaps mostly volcanic ash. It forms occasional low dunes, and is at least largely wind-borne. At a depth of 4 feet Dr. Cressman found a firm gravel beach. Neither the elevation of the spit nor its height in relation to the historic shore is known.

Some 4 miles north-northeast of the south end of the former lake and 1 mile east of Brownell (probably in the eastern part of sections 9 and 16, T. 47 N., R. 2 E.) there is a marked abandoned shore line in a peninsula

and a spit extending northward from the peninsula for $\frac{1}{3}$ mile. The spit is 400 feet wide and 8 to 10 feet high, and consists of silt and sand. It served as a camping ground for prehistoric Indians. The elevation of the spit and the shore line is about 4086 feet. Just south of Brownell, at the turn in the road, there is a gravel pit sunk 8 feet below the ground level. The exposure shows firmly cemented, very fine gravel. The deposit is almost surely a beach. Its surface stands 7 feet above the near-by historic shore line.

The first-discussed strand line is especially fresh-looking, and that 1 mile east of Brownell also appears to be young. These shore lines can hardly be more than a few thousand years old, hence cannot date from the last Glacio-pluvial. The cementation of the beach at Brownell may or may not indicate considerable age. The first and the last two of the four shore lines, which stand at about 4086 feet elevation and 7 feet above the historic shore, undoubtedly mark the same water level. The spit on the east side probably records the same level. No higher shore line was observed in the basin.

The presence of only one prehistoric shore line and that one fresh-looking, and the absence of a higher shore referable to the last Glacio-pluvial, call for explanation. Two explanations seem possible.

As mentioned above, Lower Klamath Lake owed its existence to water from Klamath River, which flows at the northwest end of the basin; its level was largely determined by the height of the river; and the lake was doomed when a man-made dike kept out the river water. Some 10 miles southwest of Klamath Falls, or 1 mile west of Keno, Klamath River enters a deep gorge, cut in lava beds, and flows across ledge and boulders in a long, foaming rapid. At the point where the water becomes swift, the width of the river narrows down to some 200 feet. If the level of the river were raised 10 feet, the width would grow by about 100 feet, and the water mass that could be accommodated would be greatly increased. The amount of the postglacial down-cutting of the gorge and the widening by weathering of the gorge

above the river is not known, but the capacity of the channel during the last Glacial was probably greater than at present.

The existence of another control of the level of Klamath River and Lower Klamath Lake was called to our attention. This is a slough connecting Klamath River and Lost River, which flows into the large Tule Basin. According to information given to Dr. Cressman by the Bureau of Reclamation in Klamath Falls, the slough left Klamath River a short distance below Klamath Falls. It carried water—at times plenty of water—when Klamath River was high.

Together these two controls were able to take care of a large increase in the water mass with a comparatively small rise of Klamath River. If it can be assumed that their capacity increased rapidly when the river had risen to a certain level, the absence in the Lower Klamath basin of a high shore line referable to the last Glacio-pluvial would be explained. Then the shore line standing at 4086 feet, or 7 feet above the historic shore, could record the water levels both of the wet last Glacio-pluvial and of the somewhat moist age just before the Christian era (Ernst Antevs, "Postpluvial climatic variations in the Southwest," *Bulletin of the American Meteorological Society*, vol. 19, pp. 190–193, 1938).

The presence of only one, relatively young, prehistoric shore line in the Lower Klamath basin can also be explained by a recent warping of the basin, that is, a relative uplift of the Klamath River gorge west of Keno, or a relative lowering of the southeastern part of the lake basin. Either event could have caused water from Klamath River to flood the southeastern part of the basin to the same level as during the much wetter Pluvial, or to a higher level.

Since the artifacts occur below the historic shore line of Lower Klamath Lake, in the bed underlying the pure peat, the problem is, Why and when was the lake so low as to permit the people to camp where they did? There seem to be two explanations of the low ancient lake level. One is climatic. A distinctly dry postpluvial age with small water supply and excessive evaporation is indicated

by the freshening of the Abert and Summer basins, among other things (Walton Van Winkle, "Quality of the surface waters of Oregon," *U. S. Geological Survey Water-Supply Paper 363*, pp. 117-123, 1914; Antevs, *op. cit.*). It came to a close about 2000 B.C., when the modern lakes were reborn, judging from their salt content, and it may have begun about 5500 B.C. During this dry age the level of Lower Klamath Lake could have fallen sufficiently to permit ancient man to camp below the historic strand line; and the artifacts occurring in the lake-shore beds could derive from this age. During the subsequent somewhat moist age the lake could have risen and freshened the shore line at 4086 feet, the level reached by the Glacio-pluvial lake. After the moist culmination had passed, the lake could have withdrawn to record the historic shore.

The other explanation assumes that at the time of the ancient people only a small part of the Lower Klamath basin lay below the Klamath River, and the larger Lower Klamath Lake, in which the pure peat accumulated, was formed *later* by inundation from the river as a consequence of a warping of the region, in accordance with our alternative explanation of the single fresh prehistoric shore line. The subsequent lowering of the lake 7 feet to the historic shore could hardly have been caused entirely by down-cutting of the Klamath River gorge, but could have been caused either by a combination of down-cutting and desiccation due to drier climatic conditions, or by a combination of down-cutting and reversed warping of the basin. The first alternative being far more probable, the conclusion would be reached that the warping occurred and ceased prior to or during the rise of the moist age before the Christian era. The buried artifacts would be older than the warping.

Thus, according to either explanation of the single ancient shore line, according to either dating, the conclusion is reached that the artifacts below the peat bed in Lower Klamath Lake antedate the moist age beginning 2000 B.C. This dating is archaeologically reasonable in Dr. Cressman's opinion.

STUDIES BEARING UPON THE PROBLEM OF EARLY MAN IN FLORIDA

E. B. Howard

Excavations at Bon Terra Farm, Flagler County, Florida. The site is approximately 29 miles south of St. Augustine, and 6½ miles south of Marineland, not over 100 yards in from the Ocean Shore Road, between it and the Inland Waterway Canal. A group known as the Explorers' Club, composed of Rollins College students, did some digging at this locality before Dr. Howard's arrival. J. H. Connery, the organizer of this college group, states that he found a chert arrowhead in a cavity which had formed in the lower jaw of a mammoth that was dug up there.

Others have known about the site and have picked up teeth and bone fragments from time to time where stripping of the rich soil or plowing has been done, or where bones have been exposed by weathering along the canal banks. Prior to the actual beginning of operations, Mr. Odom had uncovered the leg bone of a mastodon, which had been exposed in a small pit. With this as a guide, pit excavations were begun.

The surface consists of a heavy black muck and sand layer, about 34 to 44 inches thick, the upper 20 to 24 inches comprising the black muck, and the rest of it grading irregularly into a dark sand, stained by the carbonaceous material above it. This rests upon the coquina, but here and there is separated from it, in pockets, by a clean white coarse quartz sand. It is difficult to note a definite separation between these deposits, except that between the coquina and the overlying sands, which is quite marked. The muck layer was filled with old cypress stumps. The underground water level is near the average depth of the unconsolidated coquina.

The animal bones that were found came altogether from the deposits overlying the coquina, from both the black muck layer and the dark sand which is difficult to separate from it, most of them being concentrated near the mid-point, where the carbonaceous material increases. However, mastodon bones were found resting just above the uncon-

solidated coquina in several places, and only a few inches below the present surface in others. Roots from the former cypress trees had lodged in small cracks in the bones and tusks, and many specimens were thus badly damaged. In one instance a root $2\frac{1}{2}$ inches thick had grown through the lower jaw of a mastodon. This was removed by cutting the root below and above, leaving the rest of it in place so as not to shatter the jaw. The bones which we removed were not articulated.

Some 165 specimens were collected all together in a relatively small area. There seemed to be much intermingling of different forms, but all were in place in the deposits and are unquestionably of the same age. Though careful search was made for human remains and for objects of human manufacture, none were found. Several fragments of long bone of the mastodon showed marks upon the surface which were, without much doubt, tooth marks of alligators or other animals. Of the 165 specimens recovered, 72 were identified as mastodon; 28, camel; 19, turtle; 12, deer; 7, tapir; 4 each, alligator, and unidentified artiodactyl and rodent bones; 3, beaver; 2, mammoth; 2, rattlesnake; 1, ground sloth; 2, horse; 1, stork; several unidentified fish jaws, and the rest unidentified fragments. Dr. C. L. Gazin, of the National Museum, kindly assisted in making these identifications, and Dr. Gilmore, of the same institution, kindly made the identifications of the turtle and snake specimens.

The mastodon, tapir, camel, mammoth, ground sloth, horse, beaver, turtle, and snake are without doubt extinct species, and are similar to those described from Vero and Melbourne. The deer is quite likely the same as that described by Sellards from the no. 2 bed at Vero and Melbourne. At any rate it comes from the same deposit (in place) and is undoubtedly contemporaneous. The stork, according to Dr. Wetmore, of the National Museum, represents a species allied to, if not identical with, the living jabiru of tropical America, but Wetmore points out that some confusion exists as to the proper identity of the North American Pleistocene storks. It is

probably the same form as that described by Sellards from Vero.

Invertebrate specimens submitted to Dr. H. S. Richards were kindly identified by him as: *Helisoma duryi intercalare* Pilsbry, a fresh-water gastropod from both the Pleistocene and the Recent of Florida; *Euglandina rosea* Ferussac, a land gastropod; *Mylinia lateralis* Say, a marine species, characteristic of the Anastasia formation. Both of the last two forms are also known from the Recent as well as the Pleistocene. This, therefore, throws little light upon the age of the deposits. Mr. Paul S. Conger, of the Carnegie Institution, who examined samples of the muck and sand layers, found no diatoms in them.

At another place on the farm it was necessary to dig a good-sized trench in order to try to drain the site, as it was about the lowest spot in that area. Here the black muck was somewhat thicker, and in places almost a peat, very black and heavy. Investigation showed that there were several spots in the white sand below the black muck layer where the water bubbled up as in a spring. There were found here a few specimens of mastodon bone and tusk, and many fragments of turtle carapace. However, the second site differed from the first in that here the bones were below the water level, whereas at the first they were, at the lowest, just above the water level. This made many difficulties and caused uncertainty as to the exact location of specimens in the black muck. If this particular spot was actually a spring of some kind, then any association of artifacts with the bones would be fortuitous, and therefore not good evidence of actual association. It was decided to fill in the excavation and abandon this site, returning to the first, where excavations were continued as long as funds allowed.

These investigations showed that animal bones can be found in the greater part of the farm below the wooded parts and between the woods and the canal. The bones seem to have been scattered so that specimens of a number of forms are intermingled. These appear to be similar to those discovered at Vero and Melbourne. No human bones or

artifacts of any kind were found at all. The statement made a few years ago, already referred to, that a chert arrowhead had been found in a cavity of a mammoth jaw does not impress one as particularly good evidence of contemporaneous association, since the bones were below the level of standing water, and water bubbled up through the sand below as in a spring. This could easily have caused the mingling of artifacts and bones of different ages, and the arrowhead could well have worked its way from nearer the surface through the muck and sand, which was softened by permanent water at and above the level of the bones.

What scattered the bones over this comparatively small area of low land? This site is only about a mile from the present ocean beach and is separated from it by what is locally called hammock land, and by other and narrower low swampy stretches, with sand dunes intervening. The long axes of these narrow swampy stretches are at slight angles to the line of the beach. The Matanzas River seems to have extended farther south at some time in the not very far distant past, and although the site is at present between the Matanzas and Halifax rivers, it is nearer the present course of the former, and may have formed part of this sluggish stream before it was filled up at this point. Whether or not the Matanzas actually made its way through what is now Bon Terra Farm, it is evident that a section through the area which was investigated reveals the same formation as that described in geological reports covering other parts of the east coast of Florida.

There has been only slight shifting of the land relative to the sea along Florida's east coast during the present geological era. This indicates that since the beginning of the Pleistocene the sea has never covered this region very deeply, nor has the land stood much higher than it now does. In these moderate shiftings of the strand line sand dunes have been formed, stream beds filled up with alluvium, and shallow ponds and marshes left here and there. One can actually see taking place today, at various points

along the coast from St. Augustine south, many of the later stages which have culminated in the present topography at Bon Terra Farm. First, during the Pleistocene, streams cut into the coquina, after a slight emergence of the land, followed later in this period by a depression of the land, during which an accumulation of sand and muck took place. Fresh-water ponds, some perhaps fed by springs, were formed, where animals came for water and to feed upon the plants.

The remains of these animals could not have been washed any very great distance, since there is no evidence that the land was ever high enough during the Pleistocene for rapidly flowing rivers and streams to form. Nevertheless there is evidence, in the lack of articulation of the bones and the great mixture of so many different forms, that some fairly strong natural force had suddenly operated upon the exposed skeletons as found in these deposits. Many suggestions come to mind that might account for such a condition, but since they would be guesses, and could not be proved satisfactorily by the evidence, it seems best to give only the facts.

With the exception that no human remains were discovered at Bon Terra as at Vero and Melbourne, all the skeletal material present is similar to species found at these two places. Not as many different types were found at Bon Terra, since only a relatively small area was excavated; undoubtedly further work would increase the number of forms. Nevertheless one can be reasonably certain that the types of animal found here lived in the same region contemporaneously, and that there was no mixture of types of different ages. There is also reasonable assurance that the various species discovered represent extinct types. The particular type of deer found may have continued into recent times without much change, but it was unquestionably associated with remains of the tapir, camel, ground sloth, and other extinct forms in the undisturbed deposits resting above the coquina, and therefore should be considered as having existed contemporaneously with them.

The excavations add something to the picture of that period of Florida's prehistory which is believed to date from somewhere between the end of the Pleistocene and the beginning of recent times—a hazy period, to be sure, but one which it does not seem possible to fix more definitely at this time. The site seems to be an extension northward of the geological formation found at Vero and Melbourne, and gives us another locality where extinct animal bones occur in deposits that leave little doubt of the animals' having once existed together in the same region.

Tentative list of fauna from Bon Terrá

Alligator (sp. ?)
Castoroides ohioensis
Crotalus adamanteus
Equus leidyi
Elephas (columbi ?)
Jabiru (Mycteria ?)
Odocoileus (sp. ?)
Paramylodon harlani
Tanupolama myrifica
Tapirus veroensis
Turtle: Terrapene
Pseudemys
Trachemys

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